AD NUMBER

AD294903

NEW LIMITATION CHANGE

TO

Approved for public release, distribution unlimited

FROM

Distribution authorized to U.S. Gov't. agencies and their contractors; Administrative/Operational Use; NOV 1962. Other requests shall be referred to U.S. Army Transportation Research Command, Fort Eustis, VA.

AUTHORITY

USAAMRDL ltr, 13 Oct 1976

U. S. ARMY
TRANSPORTATION RESEARCH COMMAND
FORT EUSTIS, VIRGINIA

CRASH INJURY EVALUATION

MILITARY TROOP SEAT DESIGN CRITERIA

November 1962

Contract DA-44-177-TC-802

TCREC Technical Report 62-79

prepared by:

AVIATION CRASH INJURY RESEARCH
PHOENIX, ARIZONA
A DIVISION OF
FLIGHT SAFETY FOUNDATION, INC.
NEW YORK, NEW YORK

DISCLAIMER NOTICE

When Government drawings, specifications, or other data are used for any purpose other than in connection with a definitely related Government procurement operation, the United States Government thereby incurs no responsibility nor any obligation whatsoever; and the fact that the Government may have formulated, furnished, or in any way supplied the said drawings, specifications, or other data is not to be regarded by implication or otherwise as in any manner licensing the holder or any other person or corporation, or conveying any rights or permission, to manufacture, use, or sell any patented invention that may in any way be related thereto.

ASTIA AVAILABILITY NOTICE

Foreign announcement and dissemination of this report by ASTIA is limited.

All distribution of this report is controlled. Qualified users should request from

Commanding Officer
U. S. Army Transportation Research Command
Fort Eustis, Virginia

The information contained herein will not be used for advertising purposes.

HEADQUARTERS
U. S. ARMY TRANSPORTATION RESEARCH COMMAND
Fort Eustis, Virginia

This report was prepared by Aviation Crash Injury Research (AvCIR), a division of the Flight Safety Foundation, Inc., under the terms of Contract DA 44-177-TC-802. Views expressed in the report have not been reviewed or approved by the Department of the Army; however, conclusions and recommendations contained therein are concurred in by this Command.

It has long been known that the G-load factors specified in military specifications applicable to the design and manufacture of troop seats utilized in Army aircraft are not commensurate with human tolerance to force. This point has been stressed in every report published by AvCIR as a result of accident investigations, aircraft and mock-up evaluations, and dynamic crash experiments.

Until now, however, too little was known about the kinematics of an aircraft crash to comment other than in a general nature relative to proposed changes in troop seat design criteria.

This report contains the results of a careful analysis of troop seat deficiencies conducted over the past three years. For the first time, available data have been translated into terminology which is meaningful to engineering personnel. Utilization of the information contained herein may not produce the ultimate in troop seat design; it will, however, produce a seat that is representative of the current state of the art and will greatly reduce the incidence of needless injury and death attributable to troop seat failure in survivable-type Army aircraft accidents.

FOR THE COMMANDER:

Kenneth B. Abel

KENNETH B. ABEL
Capt. USA
Adjutant

APPROVED BY:

William J. Nolan

WILLIAM J. NOLAN
USATRECOM Project Engineer

Task 9R95-20-001-01
Contract DA-44-177-TC-802
November 1962

MILITARY TROOP SEAT DESIGN CRITERIA

Report of Crash Injury Evaluation
AvCIR 62-9

Prepared by
Aviation Crash Injury Research
A Division of
Flight Safety Foundation, Inc.
2871 Sky Harbor Blvd.
Phoenix, Arizona

for

U. S. ARMY TRANSPORTATION RESEARCH COMMAND
FORT EUSTIS, VIRGINIA

CRASH INJURY EVALUATION

By

James W. Turnbow, Ph. D.

Victor E. Rothe

Gerard M. Bruggink

Harold F. Roegner

CONTENTS

CONTENTS (Cont'd.)

ILLUSTRATIONS

ILLUSTRATIONS (Cont'd.)

SUMMARY

Strength requirements set forth in military specifications governing the design and fabrication of troop seats currently utilized in Army aircraft were analyzed. The analysis was made in light of accident experience with this seat, human tolerance as presently known, and accelerations and forces which may be anticipated in potentially survivable accidents involving Army aircraft.

The analysis revealed that the strength requirements quoted in current military specifications are considerably lower than (1) those which would be dictated by the upper limit of accelerations which can be tolerated by the occupants of the seats; (2) they were also lower than the accelerations and forces which probably occur in many Army aircraft accidents.[22*] This substantiates the observation by the Army that these seats fail under relatively minor accident conditions, thus subjecting the occupant to further hazards, especially to increased contact injuries.

On the basis of the detailed examination of current specifications, human tolerance, and impact acceleration data, it is recommended that the troop seat specifications be revised and that dynamic load factors of 25G for 0.20 second plus 45G for 0.10 second be adopted for troop seat design in the longitudinal and lateral directions and 25G for 0.10 second for the vertical direction. In addition, an energy absorption capability must be incorporated into the seat system to reduce the vertical accelerations on the occupant, which would frequently exceed 25G, to a tolerable level.

* Numbers refer to the references at the end of this report.

CONCLUSIONS

Based upon the information contained in this report, it is concluded that:

1. Troop seats built to specifications MIL-S-5804B and MIL-S-27174 fail under relatively moderate impact conditions, exposing the occupants to unnecessary injury or death.

2. The most significant deficiencies in the above-cited specifications are the design load factors. They are incompatible with known human tolerance to abrupt accelerations and with impact acceleration levels which may be expected in potentially survivable Army aircraft accidents.

3. Revision of the specifications, with particular emphasis on increasing the design load factors as recommended in this report, will reduce the incidence of seat failures and provide protection for the occupants commensurate with human tolerance to acceleration and consistent with the strength and energy-absorbing characteristics of modern Army aircraft.

RECOMMENDATIONS

Based upon the foregoing conclusions, it is recommended that:

1. Applicable military troop seat and related specifications be revised to provide increased occupant protection in potentially survivable crashes.

2. All revisions of the applicable specifications be based upon the following design load factors:

   a. Longitudinal and Lateral Design Loads: The seat, its support system, and occupant restraint system should, individually and in combination, be capable of maintaining 25G for 0.20 second and 45G for 0.10 second in the pelvic region of a suitable anthropomorphic dummy having a weight and mass distribution of that of the heaviest occupant expected. Progressive plastic deformation of the seat and restraint system is permissible provided (1) complete failure and (2) subsequent injurious situations do not occur.

   b. Vertical (Headward) Design Loads: The seat, its support system, and the occupant restraint system should, in combination, be capable of continuously maintaining 25G±5G in the pelvic region of the dummy described in (a.) above.* while deforming through at least 12 inches of vertical travel with respect to the airframe and, where possible, up to 15 inches or more of vertical travel.

---

* See page 52 , paragraph 3: Effect of Varying Occupant Weight.

EVALUATION OF TROOP SEAT SPECIFICATIONS

INTRODUCTION

Emphasis in aircraft accident investigation, until recent years, was placed on finding the cause of the accident. Very little effort was expended and few organizations were interested in the crash injury aspects of aviation safety. In recent years, however, increased interest has been indicated and a considerable amount of effort is being expended in improving the design of aircraft structures and components in an attempt to reduce the exposure of aircraft occupants to unnecessary injury or death when involved in aircraft accidents. The purpose is to increase the rate of survival in those accidents which will occur. This increased interest in improving the survival rate has been particularly true in the Army aviation program.

The objective of this study was: (1) to evaluate the requirements set forth in applicable troop seat specifications in the light of human tolerance to abrupt acceleration, as known at this time, and the accelerations and forces which may be anticipated in accidents involving Army aircraft, particularly helicopters and (2) to develop design criteria which may be used in the revision and improvement of applicable specifications.

ANALYSIS OF SPECIFICATION REQUIREMENTS

Accident experience has shown that seats built to MIL-S-5804B (24 September 1957) and MIL-S-27174 (8 April 1960) fail structurally when subjected to moderate crash forces which leave the environmental structure completely or substantially intact. This indicates that the design requirements set forth in the specifications are not compatible with the loads experienced in potentially survivable accidents.

Figure 1 shows the various components in a troop seat of current design.

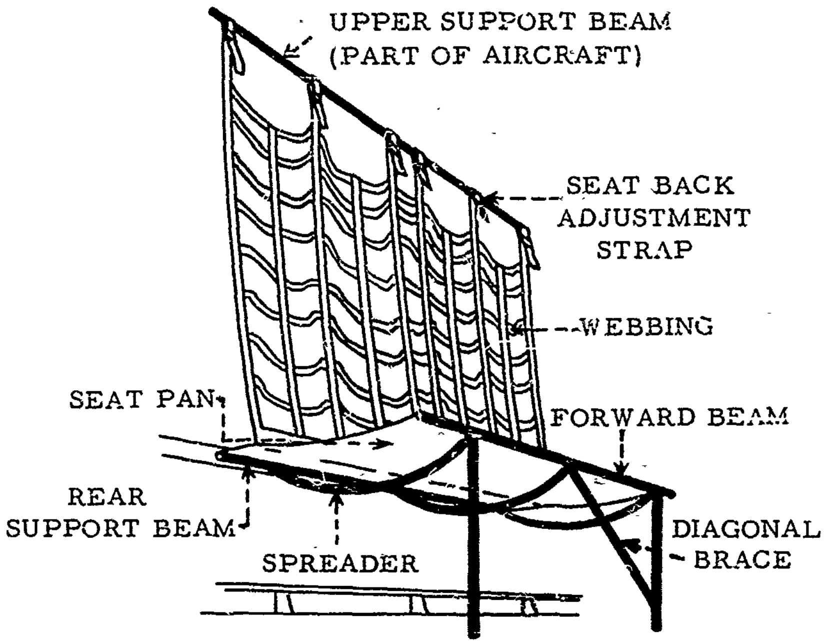


Figure 1. A Typical Troop Seat (Three-Man, Type F-2).

The specifications require that the troop seats be subjected to, and withstand, the ultimate static loads given in Table 1. For convenience, the figures have been converted into G units, which are based on a 200-pound occupant.[3]

TABLE 1
ULTIMATE LOADS (STATIC) FOR SEAT COMPONENTS

	MIL-S-5804B	MIL-S-27174
Seat Bottom	11.0G	10.0G
Seat Back	3.0G	3.0G
Side Load	1.1G	1.1G

The strength requirements in both specifications are similar, with the exception of the seat bottom (11G versus 10G). Loads on the seat bottom may be considered equally distributed over the rear and front support beams. This leads to some interesting speculation on the loading of the seat legs. According to the specification, the load-carrying capability of these legs is 1,000 pounds each. Making the conservative assumption that not more than half the occupant's weight is supported by the seat legs, this would give the legs a 10G strength. However, for a three-man seat the center leg is optional, which implies that the resistance against vertical loads would be reduced to about $\frac{2000}{300} = 6.7G$, since a three-man load would be supported by two legs. In the same manner, the strength of the four-man seat with three legs would be reduced to 7.5G.

The side load requirements for this seat form an important point concerning the adequacy of the specification. The seat is required to withstand an ultimate side load of 225 pounds (1.1G) applied in line with the center line of the front support beam. Since the seats are sometimes installed alongside the cabin walls (facing inboard), this load is applied parallel to the longitudinal axis of the aircraft and should actually be considered a forward load. In fixed-wing aircraft, this is often the direction in which the component of the main crash force is applied; and for this reason, seats in such aircraft should generally have their greatest strength in the fore and aft or longitudinal direction. The foregoing should make it clear that in the case of the troop seat design requirements, the situation is exactly reversed, that is, the seat has its lowest strength in the longitudinal direction when it is installed as a side-facing seat.

The inadequacy of present troop seat specifications is further illustrated by a comparison of the resultants of the forward and downward ultimate load factors for (a) the troop seat, (b) the passenger transport seats (NAS 809), (c) the litter installations (MIL-S-5705), and (d) the basic structure of cargo transport aircraft (MIL-S-5705). It will be assumed that the static loads which these structures must be able to withstand when applied separately can also be sustained without failure when applied simultaneously. The results are shown in graphic form in Figure 2.

In this figure the longitudinal and vertical requirements have been combined to show the magnitude and the direction of the static load requirements for cargo aircraft structure, litters, passenger seats, and troop seats. The information in Figure 2 has been tabulated in Table 2.[3]

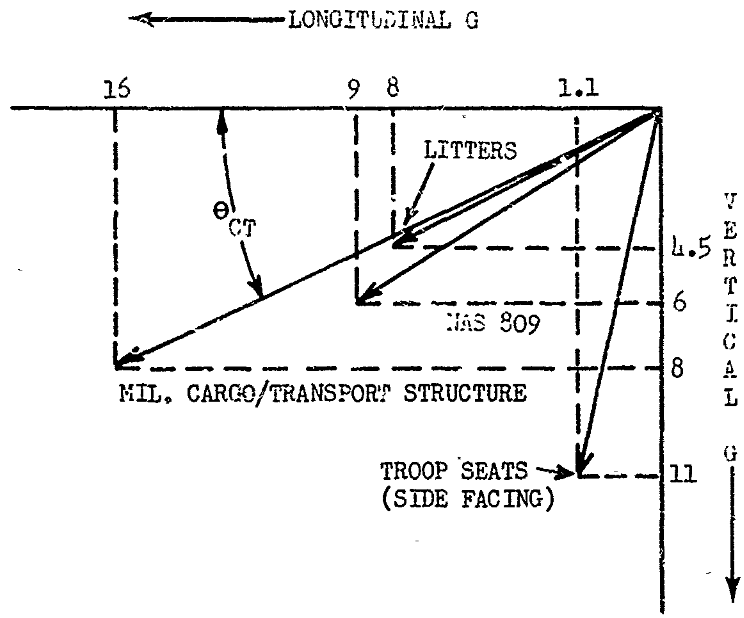


Figure 2. Static Forward and Downward Ultimate Load Requirements for Seats, Structures, and Litters.

TABLE 2
STATIC ULTIMATE LOAD REQUIREMENTS FOR SEATS, STRUCTURES, AND LITTERS

	Maximum Possible* Resultant Load Capacity	Direction** of Application
1. Cargo/Transport Aircraft Structure	18G	θ_{CT} - 27°
2. Litters	9G	θ_{L} - 30°
3. NAS 809 (Passenger Seats)	11G	θ_{NAS} - 35°
4. Troop Seats***	11G	θ_{TS} - 85°

* Neglects lateral loads.
** Measured from longitudinal axis of aircraft.
*** When side facing.

To make these data more meaningful, the various ultimate load characteristics should be compared under identical conditions of crash force angle. This has been done in Figure 3.[3] The resultant ultimate load characteristics of cargo/transport structure, litters, and troop seats have been transposed to a 35-degree vector. This angle was chosen because it coincides with the NAS 809 passenger seat requirements and falls within the range of impact conditions generally considered to be survivable. The results of this transposition are summarized in Table 3.

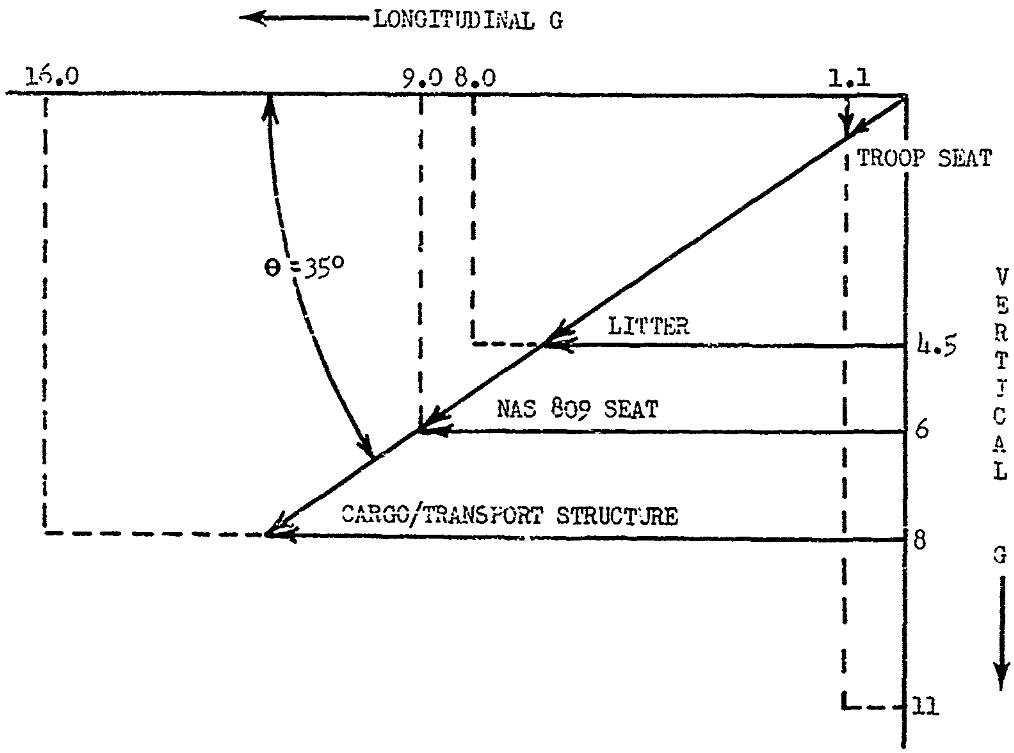


Figure 3. Ultimate Load Characteristics for Seats, Structures, and Litters at 35-Degree Crash Force Angle.

TABLE 3
THEORETICAL ULTIMATE LOAD STRENGTH OF SEATS, STRUCTURES, AND LITTERS AT 35-DEGREE CRASH FORCE ANGLE

Troop Seats	1.2G
Litters	8.0G
NAS 809 (Passenger Seat)	11.0G
Cargo/Transport Structure	14.5G

It is thus evident that the crash resistance of the troop seat under anticipated survivable impact conditions is inadequate.[3, 22]

Figures 4 through 10 depict troop seat failures which occurred during moderate impact conditions. A brief description of the accidents in which these seats were involved is given in the Appendix.

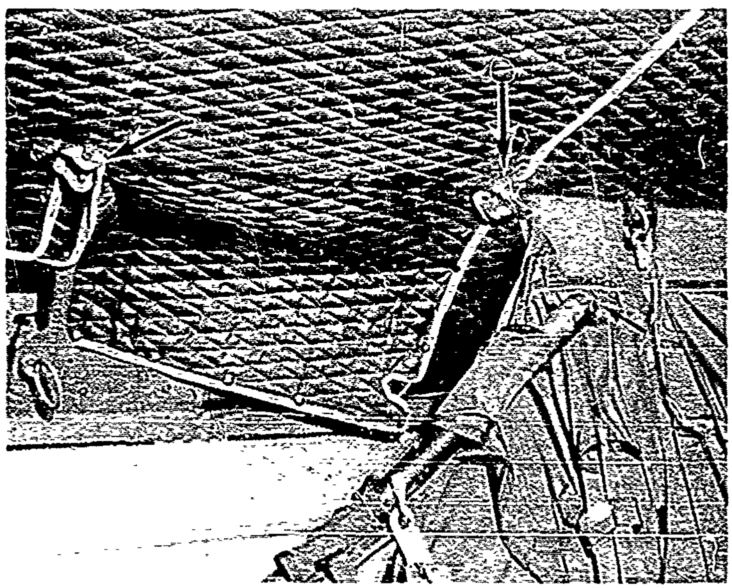


Figure 4. Rear Support Beam Failures.
Frequent failures (arrows) occur at these attachment points (Accident A).

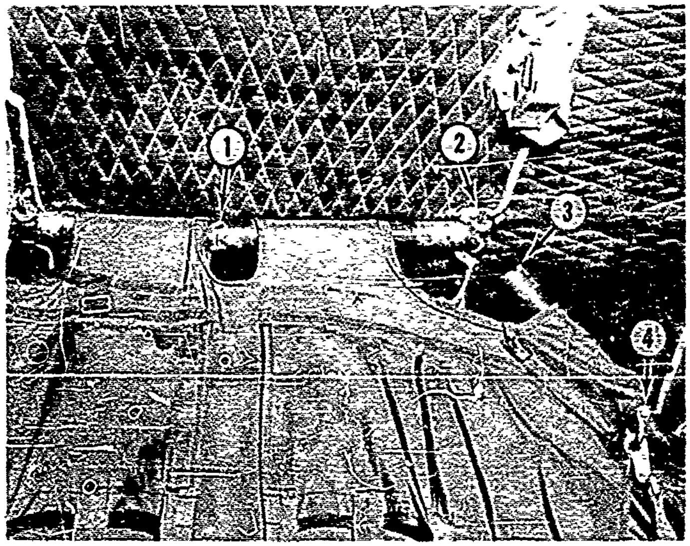


Figure 5. Typical Troop Seat Failure.
Arrow 1 indicates the manner in which some of the "D" rings were torn from the rear support. Arrows 2 and 3 depict typical seat support failures. This occupant's safety belt, Arrow 4, became ineffective due to failure of the rear support beam. (Accident A)

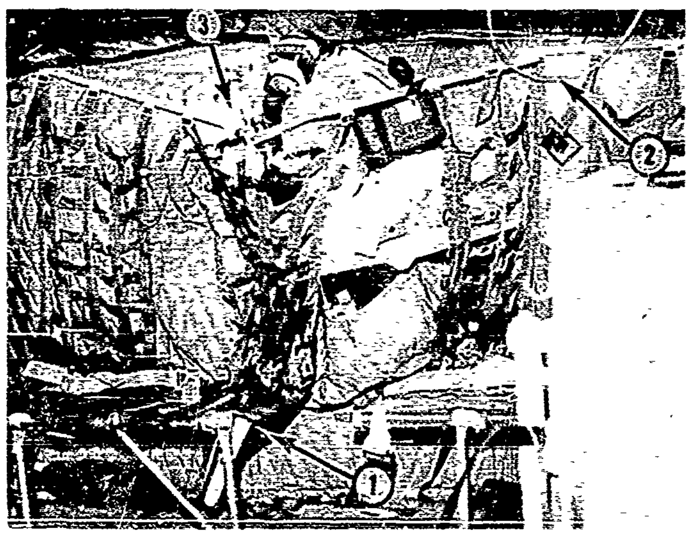


Figure 6. Troop Seat Failures in Accident B.
Arrow 1 depicts a broken front seat beam. This failure permitted the occupant to impact the cabin floor. Arrows 2 and 3 point out the failures in the upper attachment which resulted from transmission displacement.

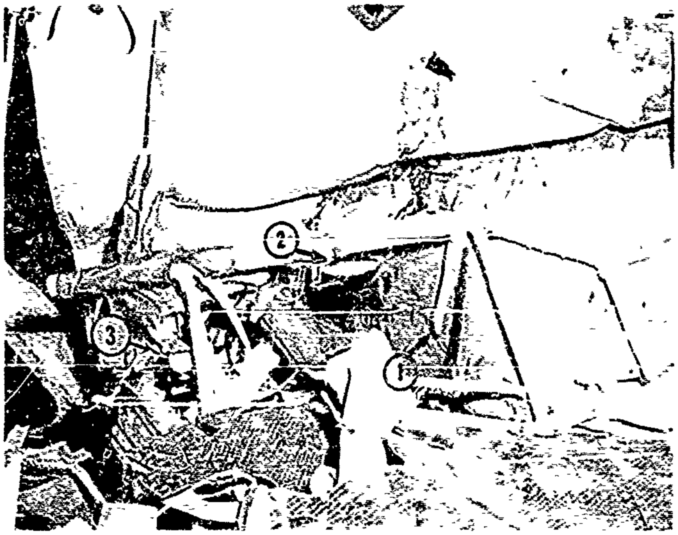


Figure 7. Failure of the Right Rear Troop Seat in Accident C. Arrow 1 indicates the broken seat spreader. Arrow 2 shows the failure of the diagonal brace. Arrow 3 indicates the position of the ground handling wheels.

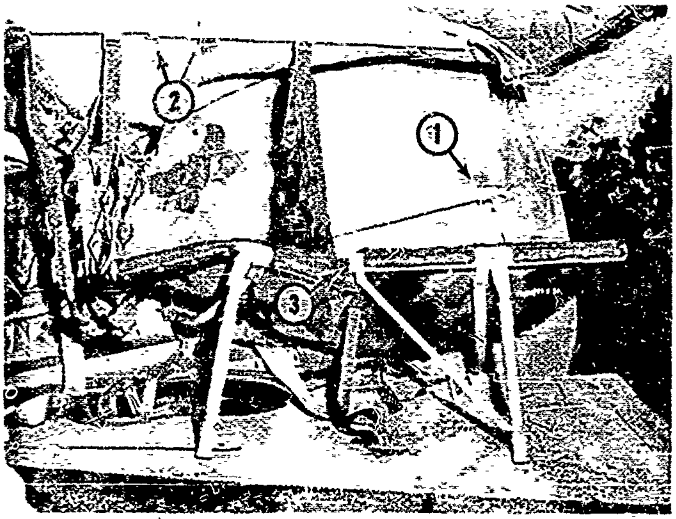


Figure 8. Failure of Left Rear Troop Seat in Accident C. This seat was set up for photographic purposes. It was originally collapsed on the floor. Arrow 1 shows the clamp where the rear support tube was anchored. Arrow 2 shows the failure of the upper longitudinal beam where the seat backs are attached. Arrow 3 shows the failure of the front support beam at a hole drilled through the tube.

Figure 9. Overall View of the Seat Damage in Accident D. Seat spreaders were torn free, seat backs were torn, and seat legs were broken.

Figure 10. Broken Front Support Beam, Seat Legs, and Loose Seat Backs in Accident D.

HUMAN TOLERANCE AND IMPACT ACCELERATION

As shown in the previous section of this report, the military troop seats presently utilized in Army aircraft and built in accordance with MIL-S-5804B, have been subject to gross failure even under moderate impact conditions. Examination of the specifications governing the design and construction of these seats strongly suggests that the reason for these failures is that the load factors to which the seats are designed are unrealistic and incompatible with the apparent crash resistance of both the structure of the occupiable sections of the aircraft, and the human anatomy itself.

Since the integrity of occupant support systems is the most critical factor in preventing injuries or fatalities in a potentially survivable accident, it would appear logical to design the seats and occupant restraint systems to load factors which parallel those of the basic structure and approach the human tolerance to accelerations.

Based upon the foregoing, a study has been made of the available information and data on these two subjects. Following is a discussion and analysis of the more important factors.

HUMAN TOLERANCE TO ABRUPT ACCELERATION

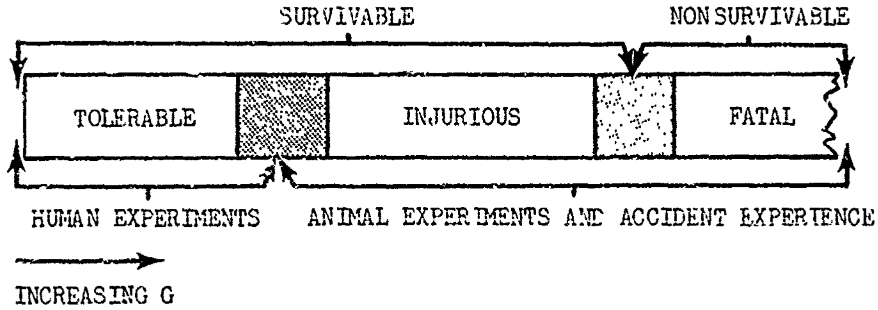
With respect to tolerance by the human body, accelerative stresses are usually divided into three categories, as follows:

1. Tolerable limits. These are the acceleration limits as set by voluntary subjects in experimental work and as deduced from accident experience. The subject is not incapacitated, although minor trauma, including abrasions, etc., not requiring medical care is acceptable if it does not impede an immediate escape attempt.

2. Injurious limits. These are associated with moderate or severe trauma and/or incapacitation, but with survival ensured with prompt medical care. The subject may be unable to extricate himself from the wreckage in time to avoid death, by drowning or fire.

3. Fatal limits. These are based upon nonsurvivable trauma as a direct or indirect result of excessive force application upon the body.

Diagrammatically, these limits can be presented as follows. The shaded areas indicate the transition zones.



It should be noted that each type of restraint system has its own tolerable-injurious-fatal pattern depending upon its effectiveness as a body support. It would appear that the design target for a given restraint system should extend beyond the tolerable range to ensure maximum survivability under the most adverse conditions; that is, some injury should be considered acceptable.

MAGNITUDE AND DURATION

Acceleration experiments have demonstrated that human tolerance to acceleration decreases with an increase in the magnitude and/or the duration of the acceleration pulse, as indicated in the curves shown in Figures 11 and 12.[8,12]

The data presented in Figure 11 are based on tolerance to acceleration perpendicular to the spine (transverse G). The lower curve in the figure indicates that the tolerable limit is about 45G for a period up to .044 second, at which point the magnitude decreases as the time of exposure increases. An acceleration of only about 9G was voluntarily sustained for a period of 2 seconds. In obtaining the data for Figure 11, the subjects were restrained by seat belt, thigh straps, shoulder harness, and chest straps. None of the subjects were injured or debilitated. The upper limits for moderate injury are shown by the dashed line in the figure, which forms the boundary between moderate and severe injury areas.

Figure 12 presents similar information on human tolerance to acceleration parallel to the spine (head-to-foot). Body support used in developing the data shown in Figure 12 consisted of seat belt and shoulder harness. The data indicate that accelerations of 16G for a pulse duration of .04 second were tolerated without shock or injury. The tolerance then decreases to approximately 10G when the duration is increased to .1 second and further decreased with longer durations. It will be noted in Figure 12 that the limits upon which present ejection-seats are designed lie in the area of moderate injury. *

DIRECTION OF FORCE APPLICATION (BODY ORIENTATION)

In a discussion of the effects of magnitude and duration of acceleration, it becomes readily apparent that the direction of force application plays a significant role in human G tolerance to abrupt acceleration.

Examination of the curves in Figures 11 and 12 shows that this tolerance is considerably greater in a direction perpendicular to the spine (transverse G) than in a direction parallel to the spine. Two of the reasons for this difference in tolerance are:

> First, the skeletal configuration and mass distribution of the human body are such that loads resulting from vertical accelerations cannot be as readily distributed over a restraint system as can loads resulting from horizontal accelerations. Therefore, vertical loads generally result in a greater stress per unit area than transverse loads.
>
> Second, the viscera have more freedom of movement (displacement) in the vertical plane or long axis of the body than in the horizontal plane. Consequently, impact parallel to the spine causes more strain on the suspension system of the viscera than an equivalent impact perpendicular to the spine.

The variation in human G tolerance with respect to body orientation is best demonstrated by a comparison of ejection-seat and free-fall

* It must be noted that the data shown in Figures 11 and 12 were obtained under conditions involving only one degree of freedom. Under actual accident conditions, accelerations in all three coordinate directions may be expected to occur either simultaneously or with random time phasing. Under such conditions, the tolerances shown in the figure would conceivably be reduced. Further research is needed to determine the effects of simultaneous or random phased accelerations in the lateral, longitudinal, and vertical directions.

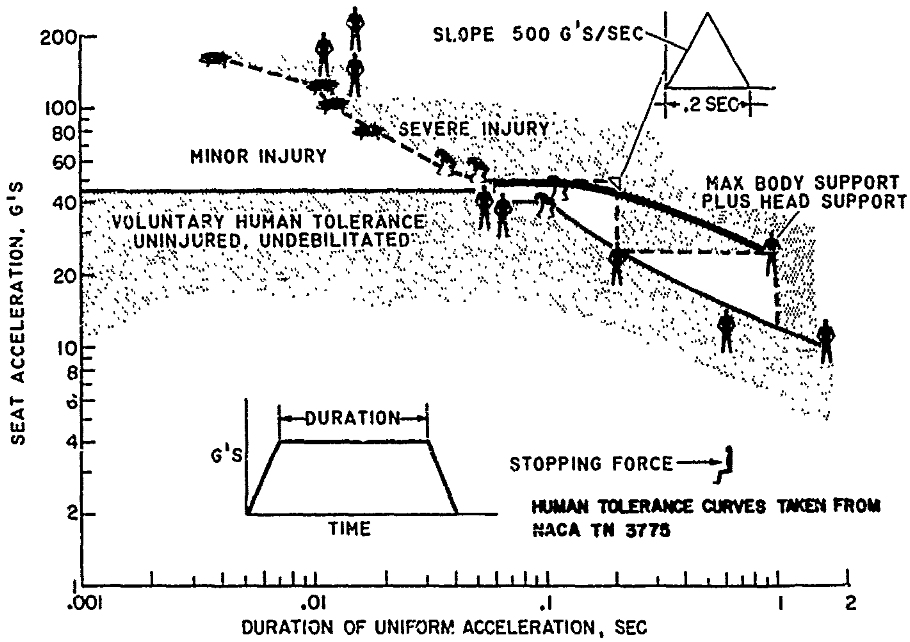


Figure 11. Tolerance to Acceleration Perpendicular to Spine With Maximum Body Support.

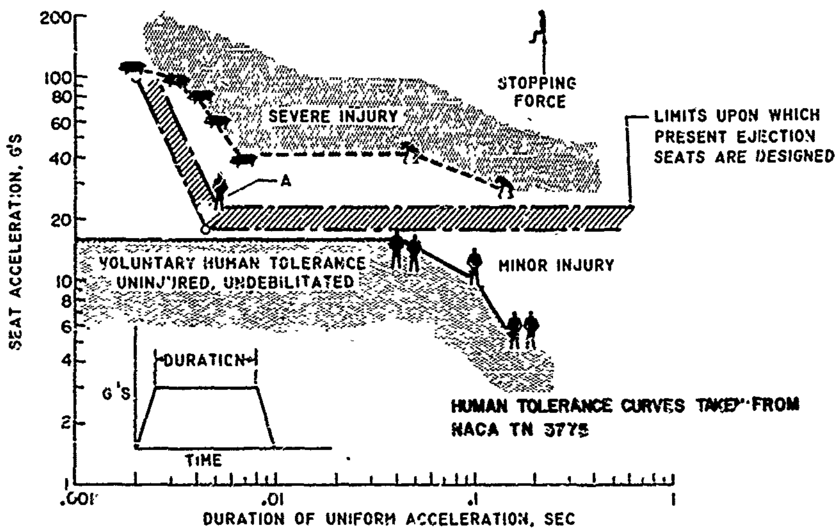


Figure 12. Tolerance to Acceleration Parallel to Spine With Lap Belt and Shoulder Harness.

experience. It is generally accepted that, for minor or no injury, the maximum tolerance to vertical acceleration for a properly seated and restrained subject is 20G acting for periods up to 0.1 second. During ejection-seat experiments, compression fractures of the vertebrae have been produced at the 26G level. In a study of free-fall accidents, it was concluded that the human body has withstood an estimated 200G (for very short intervals) during which the force acted transverse to the long-axis of the body.[5] This so-called miraculous survival in free-fall accidents demonstrates the body's high tolerance to transverse deceleration when properly supported in a prone, supine, or sideways landing on sand or ductile sheet-metal structure.

METHOD OF BODY RESTRAINT

The purpose of a restraint system is to enable an aircraft occupant to participate in the acceleration of his environment. The limitations associated with the various types of restraint systems are governed by the following factors:

1. Force Distribution. The greater the contact area between the body and the restraint system the less the force experienced per unit area. This is illustrated in the following chart which is based upon a 10G deceleration and a body weight of 170 pounds.

	Approximate Contact Area (Sq. in.)	Approximate Load (psi)
2-inch seat belt	40	42
3-inch seat belt	60	28
Aft-facing seat	210	8

2. Residual Freedom of Movement. Unrestrained body components tend to displace in a direction opposite that of the applied crash force due to the inherent inertia of the unrestrained parts. The extent of the displacement is determined by the arrangement of the restraint system. When the upper body is free to move, the impact tolerance can be seriously impaired. For example, in a situation where only a seat belt is used with a forward-facing seat, the upper torso will rotate forward over the belt during a rearward acceleration of the seat. This action brings the

spinal column into alignment with the applied force and can actually result in tension in the upper torso. Further complications may be caused by the whipping action of the head and neck when the chest is suddenly arrested by contact with the thighs.[7]

SEAT BELT RESTRAINT

Since the tolerable and injurious G limits increase with increased distribution of the accelerative force over the entire skeleton, and since the seat belt in forward-facing seats constitutes a minimum of body support, it follows that this popular restraint system is associated with the lowest tolerable, injurious, and lethal G limits.[4] Although exact information is not available on the tolerance limits associated with seat belt restraint only, the following estimates are found in the literature:

Pinkel	-	17G at 0.26 second	---Ref. 13
Pesman	-	15G	---Ref. 12
Von Gierke	-	10-20G	---Ref. 8

When restrained by seat belt only, as customary in most light aircraft and in the transports, the occupant's body has a tendency to bend around the seat belt during rearward acceleration. This is commonly referred to as "jackknifing" (Figure 13). If this bending of the body occurs at its natural joint, the hips, the strain on the spine will be nominal. When bending occurs at a higher level, such as in the upper lumbar or lower thoracic region, due to improperly installed or used seat belts, spinal injuries may result from the flexing of the spine.

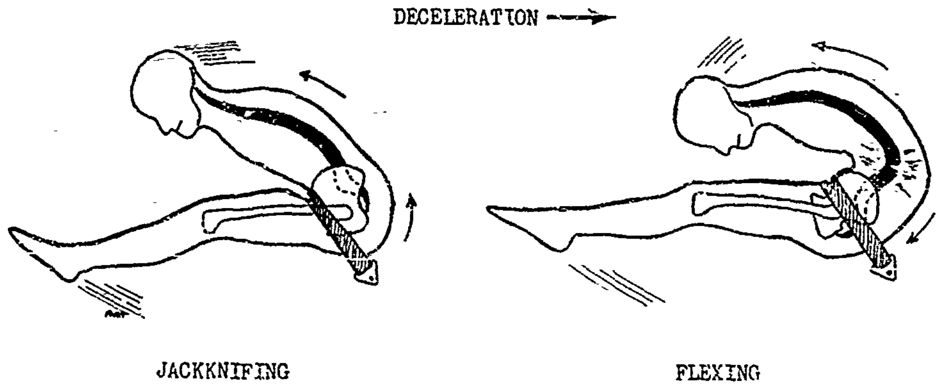


Figure 13. Body Jackknifing and Flexing.

A review of the inherent limitations of seat belt protection in aircraft accidents is not complete without considering the practical limitations imposed by environmental factors. The seating configuration in most aircraft is such that the occupants seldom have an unobstructed path for their flailing extremities and upper torso. Although environmental structure within striking distance can be made non-injurious to a certain extent, accident experience shows that in many cases the protection offered by seat belt restraint is limited not only by the ultimate strength of the belt but also by the injurious aspects of the occupant's surroundings.

A recent AvCIR study[4] indicates that 25G (occupant weight 200 pounds) is a practical design limit for a system using seat belt only. Depending upon the physical condition of the occupant and the manner of belt adjustment, various degrees of decelerative injuries may be expected at 25G. However, with survival at stake, this risk is preferable to the unpredictable exposure of an occupant who becomes a projectile after restraint system failure and is brought to a haphazard stop inside or outside the wreckage.

SEAT BELT AND SHOULDER HARNESS

The added support obtained from a properly installed and utilized shoulder harness prevents the rotary motion of the upper torso, provides better load distribution, and reduces the dynamic response of the body as a whole to accelerative forces. Consequently, the human tolerance to acceleration will be higher under these circumstances than those in which seat belt only is used.

Although adequate upper torso restraint by means of a shoulder harness (special research model) was one of the prerequisites for Stapp's 40G sled run, it is interesting to note his comments on the standard USAF shoulder harness and seat belt. The standard USAF shoulder harness and seat belt consisted of 1-3/4-inch shoulder straps and a 3-inch-wide nylon seat belt with special 40G buckle and fittings.[21] The following is a quotation from Reference 21:

> "Tests with different harness configurations brought out the following:
>
> 1. The standard USAF harness shoulder strap and lap belt combination was unstable and inadequate with uneven application of force due to the following sequence.

A. The head and shoulders coming forward, stretching the shoulder straps and elevating the lap belt to the solar plexus level, above the center of gravity of the seated subject.

B. The pelvic girdle and lower extremities then slid forward without restraint until the trunk draped around the lap belt. This resulted in sudden pressure to the epigastrium and rib margins that was not tolerated by any subject above the 17G average applied acceleration. This agrees well with the findings of Bierman whose subjects could not tolerate more than 2,600 pounds with the same harness.

2. Using strain gages on the right shoulder strap and right lap belt, it was found that varying the relative tension of lap straps and shoulder straps varied the ratio of pull measured on the straps. A tight lap belt and relatively looser shoulder straps was the subjectively less irritating arrangement."

"The research model harness with 3-inch nylon throughout and the inverted V leg straps held the trunk in good position and distributed the impact load much better, with subjects repeatedly taking tests at 35G average deceleration and higher with no more than transient discomfort."

In conclusion, it may be stated that the advantage of the standard shoulder harness is that it not only improves tolerance to acceleration but also prevents upper torso and head contact with the surrounding structure, this being the predominant cause of fatal and serious crash injuries.

MAXIMUM BODY SUPPORT

Although maximum body support during transverse acceleration is usually limited to experimental work, it adequately serves to illustrate the effect of body restraint upon the human tolerance to accelerative forces. In this respect, it is interesting to note that maximum tolerance in forward-facing seats is always associated with the use of thigh straps or inverted V straps in combination with seat belt and shoulder harness. This prevents tipping of the pelvis and raising up of the seat belt to the upper abdomen and lower rib cage and ensures that the major portion of the accelerating force is applied to the pelvic girdle. With this type of restraint 40G has been sustained for 0.12 second without irreversible injury, and overshooting of the subject to 60G for .02 second has been tolerated as well.[21]

The use of maximum body support has been a major factor in raising the impact tolerance of the space capsule occupants. In most cases, the force is applied transversely by placing the subject in a supine position. A contoured couch, molded to fit the individual, provides optimum body support. The following impact accelerations were tolerated, for short durations,* by human subjects in a capsule configuration (in separate tests).[10]

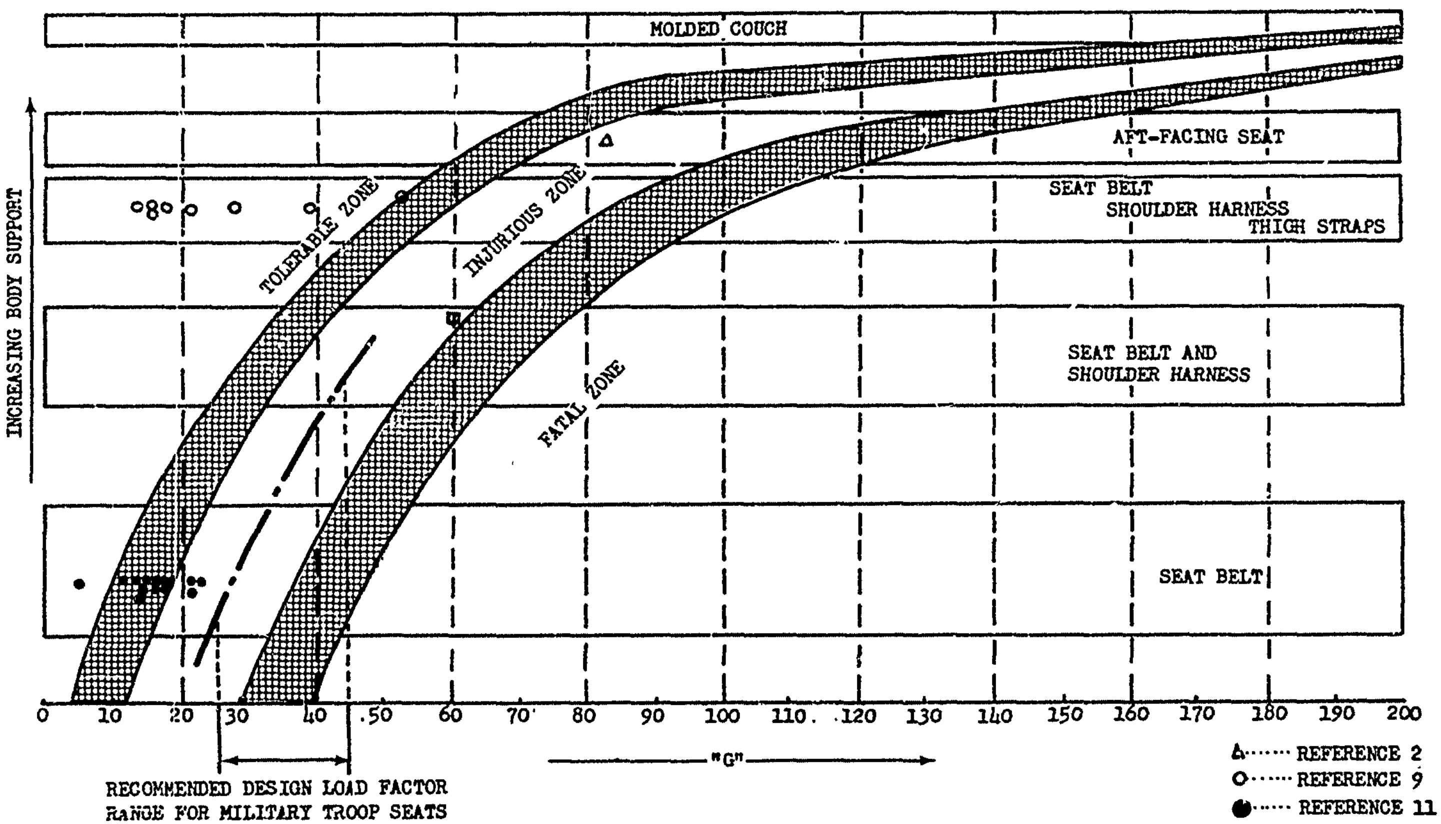
	Transverse	Lateral	Vertical
Capsule	86.6G	19.5G	32.4G
Subject	126.5G	65.0G	74.6G

SEAT DESIGN CRITERIA BASED UPON HUMAN TOLERANCE

Based upon the foregoing discussion, it is concluded that human tolerance to abrupt acceleration, from a practical point of view, is dependent upon a variety of factors. The most important controllable factors are body orientation and method of restraint. Survival of abrupt accelerations in aircraft accidents will, therefore, largely depend upon the type and strength of the seat, the orientation of the seat and the type of restraint system utilized.

A series of hypothetical curves have been prepared to show how the human tolerance probably varies when subjected to abrupt transverse acceleration under a variety of seat and restraint system combinations presently in use (Figure 14). The relative positions of these curves were deduced from the limited experimental data available. They illustrate qualitatively the relation between restraint system and tolerance but, because of the lack of sufficient data points, cannot be considered sufficiently accurate for design purposes, except for the restraint system comprising: (1) seat belt and (2) seat belt with shoulder harness and thigh straps. This would, however, suggest an intermediate position for the curve for a "seat belt plus shoulder harness" restraint system as indicated in Figure 14.

*Exact durations not published. Total change in velocity was of the order of 30 feet per second.



(The shaded areas indicate transition between the tolerable, injurious and fatal deceleration limits.)

Figure 14. Hypothetical Correlation of Restraint Systems and Human Tolerance to Abrupt Transverse Deceleration for Durations of the Order of .001 to 0.10 Second.

The final determination of seat design criteria must be based on a careful selection of design points from the currently available tolerance and crash test data with allowances for the seating configuration and restraint system desired by the user. The values selected below for the three principal directions of motion appear to offer realistic protection for occupants of military troop seats:

Longitudinal and Lateral Strength Requirements. Since military troop seats may be installed either forward- or side-facing in the aircraft, the load factors for these two directions should be the same. It is assumed that some injuries are acceptable in the more extreme accidents. On this basis, then, a further curve was drawn in the center of the injurious zone in Figure 14 and this curve was used as the basis for selection of the load factors. For a troop seat installation in which seat belts will be the only form of restraint used, the seat should thus be designed to withstand both longitudinal and lateral accelerations of 25-30G (when occupied by a 200-pound man) for a duration of 0.2 second* without gross failure. Progressive, or controlled, deformation would be acceptable.

If consideration is given to the use of shoulder harness with the seat belt, and this is strongly recommended, the tolerance of the occupant to acceleration is increased. To assure seat and restraint system integrity compatible with human tolerance in this condition, the seat and restraint system must be designed to a higher set of load factors than presently employed. Again plotting a midpoint in the injurious zone for a seat belt/shoulder harness restraint system in Figure 14, the load factor should be somewhere between 40-50G, for a duration of 0.1 second, with the added capability of maintaining 25G for 0.2 second.

Vertical Strength Requirements. Human tolerance to acceleration parallel to the spine is fairly well defined and less affected by variations in the seat restraint systems.

If it is again assumed that some injury is acceptable, it would appear that a reasonable compromise for vertical load factors would be 25G for a period of 0.10 second. (See Figure 12.)

It must be pointed out, however, that vertical accelerations of the floor structure in rotary-wing aircraft accidents can easily

*25G for 0.2 second corresponds to a change in velocity of 160 feet per second, or approximately 110 miles per hour.

exceed 25G[22], as will be shown in the next section of the report. In order to prevent the vertical acceleration of the occupant of rotary-wing aircraft accidents from exceeding the above recommended 25G, improved seat suspension systems and energy absorption techniques will be required. Further requirements for the seat with respect to the vertical acceleration inputs must thus be met. These requirements will be developed more fully in a later section.

In summary, seat and restraint systems designed to load factors of 25G in the three principal directions will provide support up to the tolerance levels of the human body when restrained by seat belt only. If a shoulder harness is used in combination with the seat belt, then the longitudinal and lateral limits should be increased to 45G for .1 second.

IMPACT ACCELERATION DATA

The purpose of this discussion is to determine whether the seat design-load-factors selected on the basis of human tolerance are compatible with impact accelerations which may be anticipated in potentially survivable accidents of both fixed-wing and rotary-wing aircraft, i.e., in which the occupiable area of the aircraft remains reasonably intact. Such an accident may be considered to be potentially survivable. Calculation of the exact forces and accelerations experienced in actual accidents is not possible because of the complexity of the structure of the aircraft. Experimental crash tests of both fixed-wing and rotary-wing aircraft have been conducted and, while limited in scope and number, provide useful data for determining accelerative loads under actual accident conditions.

The data from twenty experimental crash tests were analyzed. Fifteen of the tests were made by NACA using fixed-wing aircraft. Five of the tests were made by AvCIR using helicopters. The fixed-wing aircraft used by NACA were crashed under their own power by running them into earthen embankments sloped at various angles to give the desired impact conditions.

In the AvCIR tests, helicopters were suspended from the boom of a moving crane and dropped on a target from a height of 30 feet at forward speeds up to 30 miles per hour.

The type of aircraft used in the 20 tests, the conditions under which they were crashed, and the floor accelerations measured during the experiments are shown in Table 4.

TABLE 4

SUMMARY OF FULL-SCALE CRASH TEST - FLOOR ACCELERATION DATA

Line Item No.	Type Aircraft	Impact Angle (degrees)	Aircraft Attitude (degrees)	Impact Velocity (m.p.h.)	Location (in. from nose)	ACCELERATIONS LONGITUDINAL Peak Mag. (G)	Time of Occur. (sec.)	Pulse Dur.*	VERTICAL Peak Mag. (G)	Time of Occur. (sec.)	Pulse Dur.*	References
1	Piper J-3	55	55	42	Under Rear Seat	26.5	0.040	0.23	9	0.06	0.02	6
2	Piper J-3	55	55	47	Under Rear Seat	32.5	0.039	0.18	13	0.08	0.04	6
3	Piper J-3	55	55	60	Under Rear Seat	33.5	0.121	0.23	--	--	--	6
4	Fighter Navy FH-1	18	18	112	Cockpit Floor	20	0.06	0.18	--	--	--	1
5	Fighter Navy FH-1	22	22	112	Cockpit Floor	30	0.065	0.18	30 55	0.06 0.285	0.10 0.05	1
6	Fighter Navy FH-1	27	27	112	Cockpit Floor	140	0.065	0.09	--	--	--	1
7	Fighter Navy FH-1	4 (Ground Loop)	4 (Ground Loop)	112	Cockpit Floor	8	2.33	0.20	--	--	--	1
8	Fighter Navy FH-1	Cart Wheel 30° roll	Cart Wheel 30° roll	112	Cockpit Floor	9	0.135	—	15	2.2	0.03	1
9	C-46	5	5	81	270	2.5	0.190	0.33	2.5	0.265	0.35	14
10	C-46	15	15	93	250	10	0.120	0.22	15	0.095	0.18	14
					360	11	0.122	0.22	10	0.075	0.18	
					485	7	0.125	0.22	10	0.150	0.18	

4	Fighter Navy FH-1	18	16	112	Cockpit Floor							
5	Fighter Navy FH-1	22	22	112	Cockpit Floor	30	0.065	0.18	30 55	0.06 0.285	0.10 0.05	1
6	Fighter Navy FH-1	27	27	112	Cockpit Floor	140	0.065	0.09	--	--	--	1
7	Fighter Navy FH-1	4 (Ground Loop)	4 (Ground Loop)	112	Cockpit Floor	6	2.33	0.10	--	--	--	1
8	Fighter Navy FH-1	Cart Wheel 30° roll	Cart Wheel 30° roll	112	Cockpit Floor	9	0.235	---	15	2.2	0.03	1
9	C-46	5	5	81	270	2.5	0.190	0.33	2.5	0.265	0.35	14
10	C-46	15	15	93	250	10	0.120	0.22	15	0.095	0.18	14
					360	11	0.122	0.22	10	0.075	0.18	
					485	7	0.125	0.22	10	0.150	0.18	
					580	9	0.125	0.22	8	0.170	0.18	
11	C-46	29	29	97	185	20	0.145	0.23	25	0.175	0.21	14
					335	22	0.145	0.23	18	0.135	0.21	
					490	20	0.150	0.23	12.5	0.160	0.21	
					685	17	0.155	0.23	10	0.195	0.21	
12	Lodestar	12 (Ground Loop)	12 (Ground Loop)	67	243 312	3.5 3.5	0.265 0.260	0.12 0.12	9 9	0.275 0.275	0.09 0.09	14
				63	243 312	7 7	1.653 1.680	0.13 0.13	40 28	1.653 1.680	0.13 0.13	
13	Lodestar	16	16	109	243 312	15 13	0.195 0.185	0.25 0.25	18 16	0.180 0.215	0.22 0.22	14
14	C-82	4	4	95	Long. 138 Vert. 140	6	0.150	0.17	12	0.30	0.17	14
15	C-82	16	16	91	Long. 340 Vert. 541	15	0.07	0.10	10	0.30	0.07	14
16	H-25	45	0	42	60	45	0.11	0.07	115	0.105	0.03	22
					105	36	0.09	0.07	61	0.095	0.06	
	HUP-2	48	0	39	60	44	0.17	0.13	234	0.13	0.03	24
					105	26	.12	0.13	125	0.12	0.045	
18	HUP-2	56	0	35	60	40	0.14	0.13	200	0.12	0.03	25

9	C-46	5	5	81	270	2.5	0.190	0.33	2.5	0.265	0.35	14
10	C-46	15	15	93	250	10	0.120	0.22	15	0.095	0.18	14
					360	11	0.122	0.22	10	0.075	0.18	
					485	7	0.125	0.22	10	0.150	0.18	
					680	9	0.125	0.22	8	0.170	0.18	
11	C-46	29	29	97	185	20	0.145	0.23	25	0.175	0.21	14
					335	22	0.145	0.23	18	0.135	0.21	
					490	20	0.150	0.23	12.5	0.160	0.21	
					685	17	0.155	0.23	10	0.195	0.21	
12	Lodestar	12 (Ground Loop)	12 (Ground Loop)	87	243	3.5	0.265	0.12	9	0.275	0.09	14
					312	3.5	0.260	0.12	9	0.275	0.09	
				63	243	7	1.653	0.13	40	1.653	0.13	
					312	7	1.680	0.13	28	1.680	0.13	
13	Lodestar	16	16	109	243	15	0.195	0.25	18	0.180	0.22	14
					312	13	0.185	0.25	16	0.215	0.22	
14	C-82	4	4	95	Long. 138 Vert. 140	6	0.150	0.17	12	0.30	0.17	14
15	C-82	16	16	91	Long. 340 Vert. 541	15	0.07	0.10	10	0.30	0.07	14
16	H-25	45	0	42	60	45	0.11	0.07	115	0.105	0.03	22
					105	36	0.09	0.07	61	0.095	0.06	
17	HUP-2	48	0	39	60	44	0.17	0.13	234	0.13	0.03	24
					105	26	.11	0.13	125	0.12	0.045	
18	HUP-2	56	0	35	60	40	0.14	0.13	200	0.12	0.03	25
					105	20	0.13	0.13	188	0.115	0.06	
19	H-13	50	0	38	40	150	0.065	0.03	273	0.06	0.03	26
20	H-13	49	0	38	40	175	0.035	0.02	230	0.03	--	26

* The acceleration records obtained at floor level in the crash tests of line items No. 16 through 20 were generally composed of a series of successive individual pulses. The durations given in this table represent the total interval during which the primary decelerations occurred.

A review of the data presented in Table 4 reveals that the magnitudes of the accelerations in both the longitudinal and vertical directions were generally higher in the helicopter tests than in the fixed-wing tests. The durations of the acceleration pulses were longer in the case of the fixed-wing tests since the total change in velocity for the fixed-wing tests was equal or greater than that for the rotary-wing experiments. In both instances the test conditions yielded crashes believed to be potentially survivable, and although the tests conducted with the two types of aircraft were not directly comparable, the damage sustained by both aircraft types was comparable, and the accident conditions were typical of the aircraft types involved.

The higher vertical accelerations obtained at the floor level in the helicopter tests are expected to occur often in accidents and are associated with the operating characteristics of these aircraft and with their unique structural configuration. During helicopter accidents, vertical velocities are generally predominant, and this, in combination with the relatively small amount of crushable structure between the floor and the bottom of the aircraft, results in high vertical accelerations at the floor. Most of the fixed-wing aircraft on which crash acceleration data are available had a greater depth of crushable structure between the floor and the bottom of the fuselage than was available in the corresponding helicopters tested. The crushing of this structure resulted in a more gradual rate of reduction in velocity at floor level, i.e., deceleration. Obviously, design changes of either or both types of aircraft could ultimately change this situation.

On the basis of the foregoing analysis of "accident" data together with the preceding study of human tolerance limits, the rotary-wing aircraft apparently poses the most serious problem in providing the desired crash protection for troop seat occupants because of the "low" human tolerance to vertical deceleration and the "high" vertical accelerations associated with helicopters. The remaining discussion will, therefore, be largely centered on the helicopter problem.

Upon examination of the published acceleration data obtained from the experimental crash tests, it was found that pulse shapes which usually occur are similar to those shown in Figure 15, that is, they are either: (a) triangular, (b) half sine wave, or (c) half sine wave with a superimposed triangular peak.

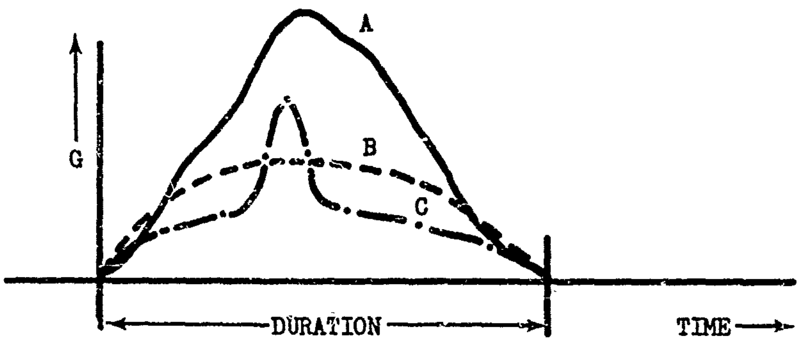


Figure 15. General Pulse Shapes Occurring in Typical Accidents.

Human tolerance data have, by contrast, been based upon a trapezoidal pulse shape in which the duration of the plateau (interval for which a constant level of acceleration was endured) is generally called the "duration." This nomenclature is illustrated in Figure 16.

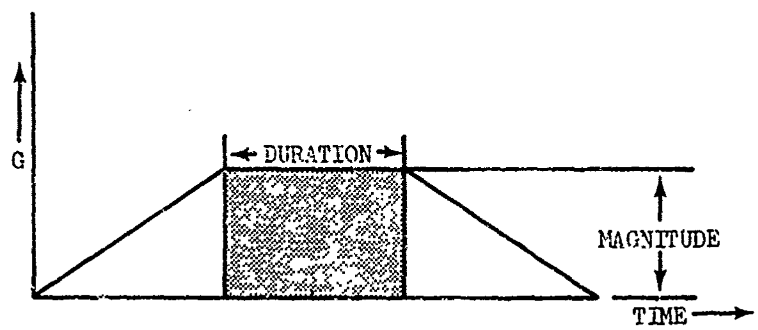


Figure 16. Pulse Shapes Used in Evaluating Human Tolerance.

In order to establish a basis for comparison of human tolerance limits with crash test data, the acceleration records obtained in the helicopter crash tests were divided into segments. The durations of the various plateau levels, as shown in Figure 17, were then established.

A summary of these data is presented in Tables 5 through 9.

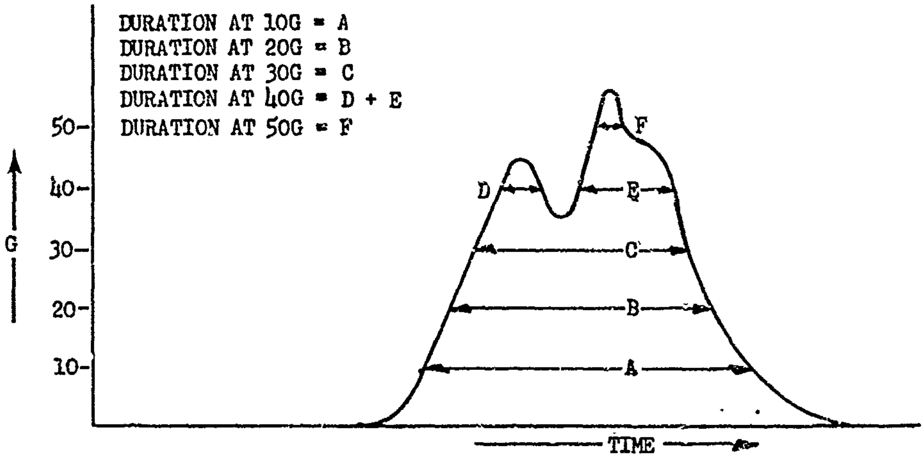


Figure 17. Subdivision of Crash Pulse Into Acceleration Levels.

TABLE 5
H-25A CRASH TEST CONDUCTED 22 OCTOBER 1960 (T-1)

Location and Plane of Measurement	Magnitude and Duration of Acceleration										Remarks
	10G	20G	30G	40G	50G	60G	70G	80G	90G	100G	Peak G
Cockpit Floor - Long.	.032	.013	.004	.001+							45
Cockpit Floor - Vert.	.022	.018	.014	.012	.009	.007	.006	.005	.004	.003	115
Cabin Floor - Long.	.04	.03	.01	.007	.005	.001					61
Cabin Floor - Vert.	.05	.03	.01	.007	.004						61
Pilot Pelvic - Long.	.017	.010									25
Pilot Pelvic - Vert.	.045	.040	.008	.005	.003						60
Side Passenger Chest - Long.	.15										9
Side Passenger Chest - Vert.	.025	.008	.005	.003	.002						56

TABLE 6
HUP-2 CRASH TEST CONDUCTED 14 JUNE 1961 (T-2)

Location and Plane of Measurement	Magnitude and Duration of Acceleration										Remarks
	10G	20G	30G	40G	50G	60G	70G	80G	90G	100G	Peak G
Cockpit Floor - Long.	.040	.016	.004	.002							44
Cockpit Floor - Vert.	.016	.014	.011	.009	.008	.007	.0065	.006	.005	.004	234
Cabin Floor - Long.	.044	.04									27
Cabin Floor - Vert.	.026	.010	.008	.007	.0065	.006	.0055	.005	.004	.003	125
Pilot Pelvic - Long.	.05	.02									2 Peaks- 50
Pilot Pelvic - Vert.	.035	.03	.025	.02	.015						55
Side Passenger Pelvic - Long.	.03	.01									25
Side Passenger Pelvic - Vert	.06	.02									25
Rear Passenger Pelvic - Long.	.015										15
Rear Passenger Pelvic - Vert.	.05	.03	.02	.01							45

TABLE 7
H-13D CRASH TEST CONDUCTED 1[illegible] JUNE 1961 (T-3

Location and Plane of Measurement	Magnitude and Duration of Acceleration										Remarks
	10G	20G	30G	40G	50G	60G	70G	80G	90G	100G	Peak G
Cockpit Floor - Long.	.014	.012	.010	.008	.006	.0055	.005	.0045	.004	.003	150
Cockpit Floor - Vert.	.01	.006	.0055	.005	.0045	.004	.0035	.003	.0025	.002	273
Pilot Pelvic - Long.	.02	.015	.012	.01	.004	.001					55
Pilot Pelvic - Vert.	.034	.025	.02	.015	.014	.01	.009	.007	.003		99

TABLE 8

HUP-2 CRASH TEST CONDUCTED 9 AUGUST 1961 (T-4)

Location and Plane of Measurement	Magnitude and Duration of Acceleration										Remarks
	10G	20G	30G	40G	50G	60G	70G	80G	90G	100G	Peak G
Cockpit Floor-Long.	.040	.01									40
Cockpit Floor-Vert.	.012	.011	.010	.009	.0065	.006	.0055	.005	.004	.003	200
Cabin Floor-Long.	.015										15
Cabin Floor-Vert.	.03	.02	.015	.01	.008	.006	.005	.003	.002	.001	188
Pilot Pelvic-Long.	.02	.013									30
Pilot Pelvic-Vert.	.035	.025	.023	.02	.01	.006	.003				75
Copilot Pelvic-Long.	.01	.004	.002								35
Copilot Pelvic-Vert.	.065	.043	.02	.001							45
Floor Pass. Pelvic-Long.	.02	.01	.007	.005	.004	.003	.002				80
Floor Pass. Pelvic-Vert.	.03	.015	.012	.009	.007	.005	.004	.002			82+
Side Facing Pass. Pelvic-Long.	.035	.02	.009								(AvCIR Experimental Seat) 40
Side Facing Pass. Pelvic-Vert.	.06	.019	.01	.003							(AvCIR Experimental Seat) 42
Rear Pass. Pelvic-Long.	.015										18
Rear Pass. Pelvic-Vert.	.50	.03	.02	.012	.009	.003					63

TABLE 9
H-13D CRASH TEST CONDUCTED 3 AUGUST 1961 (T-5)

Location and Plane of Measurement	Magnitude and Duration of Acceleration										Remarks
	10G	20G	30G	40G	50G	60G	70G	80G	90G	100G	Peak G
Cockpit Floor - Long.	.017	.007	.0055	.005	.0045	.004	.0035	.003	.0025	.002	175
Cockpit Floor - Vert.	.030	.015	.010	.007	.0055	.005	.0045	.004	.0035	.003	230
Pilot Pelvic - Long.	.04	.01	.005	.001							42
Pilot Pelvic - Vert.	.027	.02	.017	.015	.014	.007					65
Copilot Pelvic-Long.	.025	.013	.003								32
Copilot Pelvic-Vert.	.03	.02	.015	.01	.009	.007	.005	.003	.002		95

Selected sets of data from the AvCIR helicopter tests (Tables 5 and 8) have been superimposed on the human tolerance curves for longitudinal (spineward) and vertical (headward) accelerations, resulting in Figures 18, 19, and 20.*

Two points are immediately evident: (a) the longitudinal accelerations occurring in the crash tests at floor level and also in the pelvic and chest regions of the dummy "occupants" are generally below the voluntary human tolerance level, while (b) the vertical accelerations are often above both the voluntary and minor injury levels. An investigation of Tables 6, 7, and 9 readily shows that similar results will be obtained for the data presented therein.

An examination of the Tables 5 through 9 shows that only two longitudinal accelerations, other than at floor level, exceeded the voluntary tolerance level of 45G. One was recorded in the pelvic region of a dummy seated on a cushion on the floor directly behind the copilot seat (T-4), the second in the pilot pelvic region (T-3). Five similar measurements did not exceed 25G. This would indicate that the selection of a troop seat design load of 45G for 0.1 second in the longitudinal direction is a reasonable target. If the seat were also designed to fail progressively beyond these values, protection could be provided up to the maximum accelerations anticipated in most potentially survivable accidents.

* This method of comparison of human tolerance with actual crash test data has no direct mathematical basis; however, for short duration pulses (0 to .1 second) where the total ΔV is of primary concern, it is obviously conservative with respect to predicting injury.

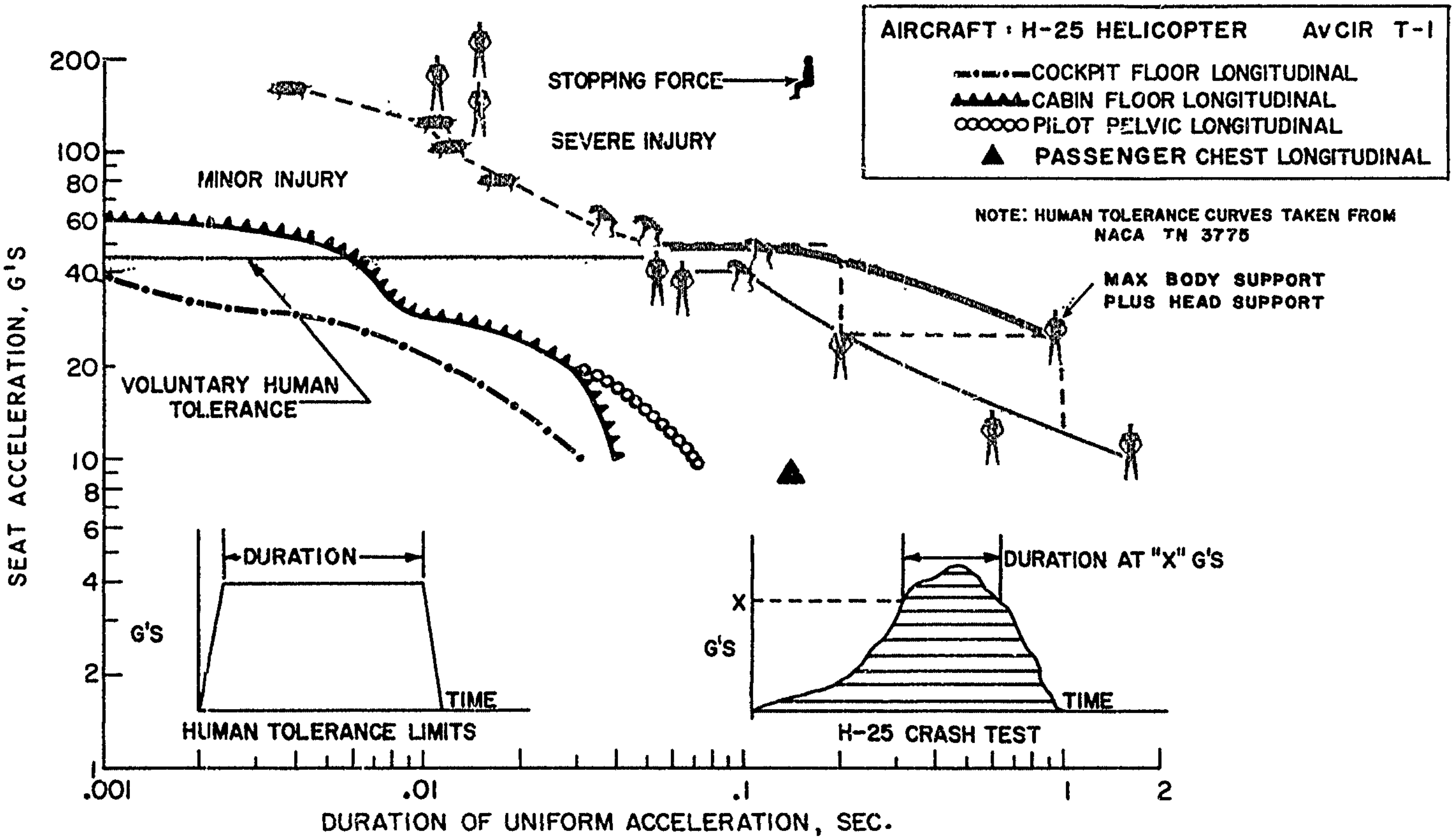


Figure 18. Comparison of Crash Test Data With Human Tolerance to Acceleration Perpendicular to the Spine With Maximum Body Support.

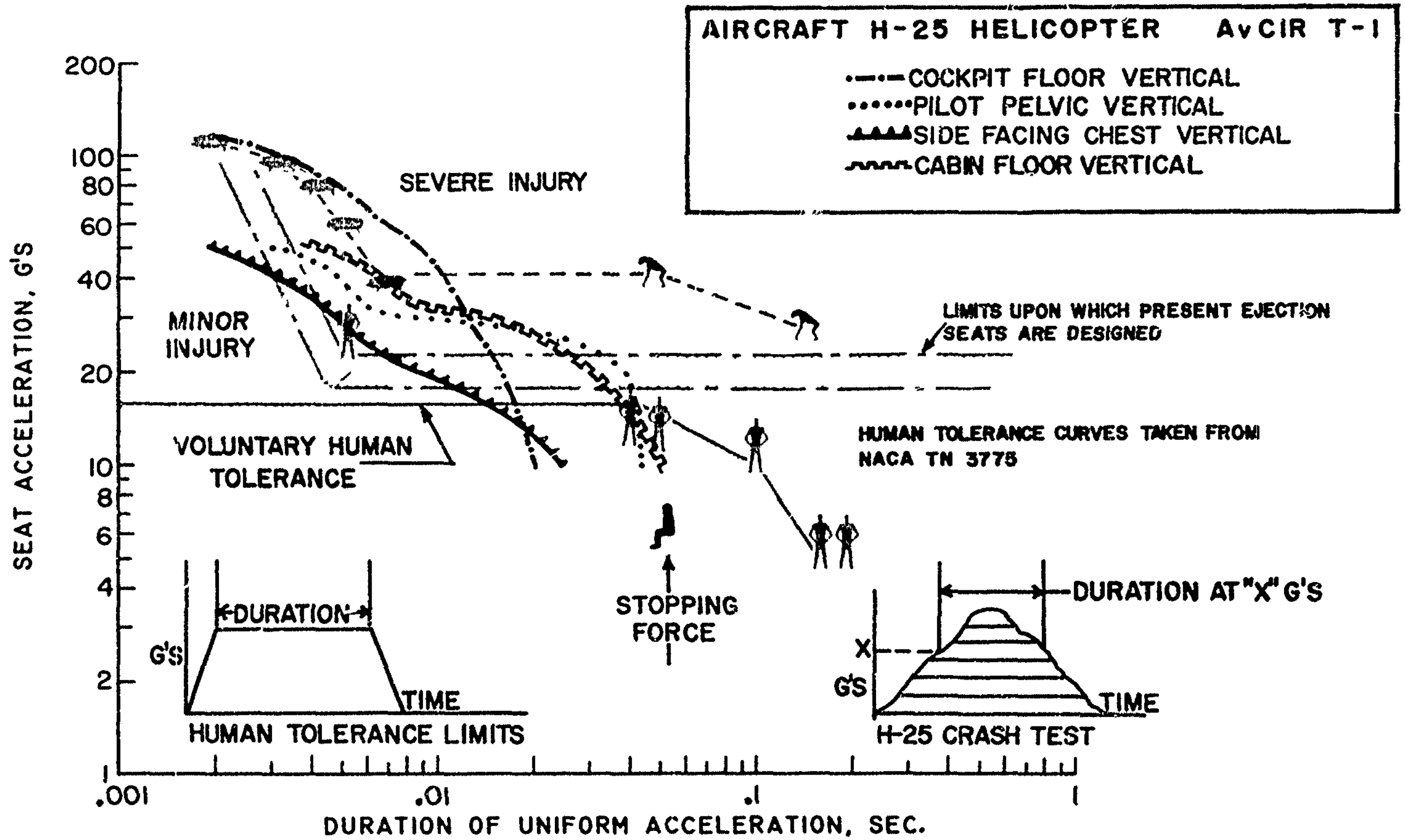


Figure 19. Comparison of Crash Test Data With Human Tolerance to Acceleration Parallel to Spine With Lap Belt and Shoulder Harness.

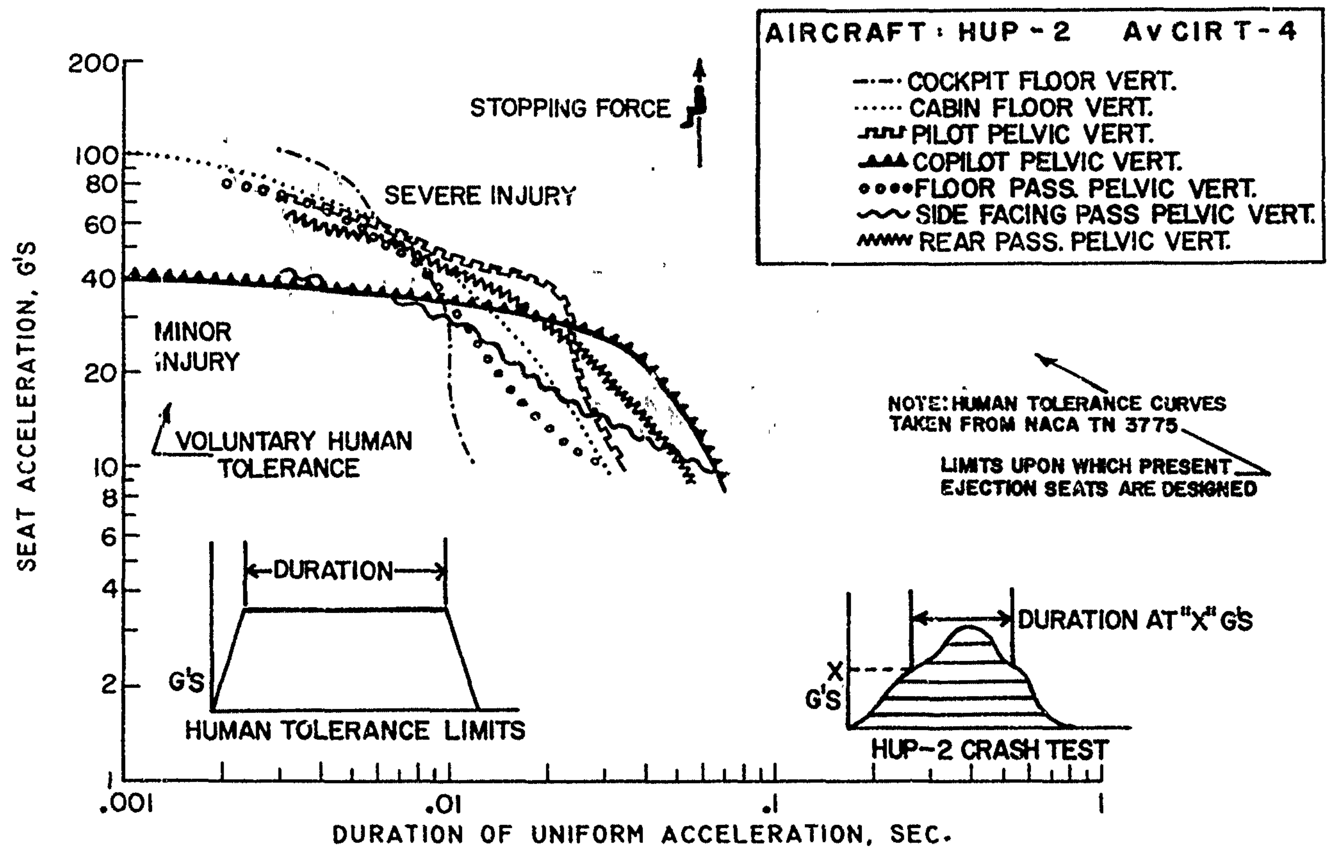


Figure 20. Comparison of Crash Test Data With Human Tolerance to Acceleration Parallel to Spine With Lap Belt and Shoulder Harness.

An examination of the curves shown in Figures 19 and 20 for the vertical (headward) acceleration indicates that this direction of loading poses the most serious problem. In almost every instance, the accelerations measured at the floor and in the pelvic regions of the dummies exceeded by a considerable margin the limits of voluntary human exposure and the limits upon which current ejection seats are designed. Figure 21 illustrates the order of magnitudes of the vertical acceleration pulses recorded in five crash tests of H-25, HUP-2, and H-13D helicopters.

Because it may be difficult to reduce the floor accelerations without serious weight penalties, it appears that some form of energy absorption must be utilized to reduce the vertical acceleration on the occupants to a tolerable level. Since human tolerance to acceleration in this direction is estimated to be approximately 25G, the seat must be designed with an energy absorption system to prevent the accelerations experienced by the occupant from exceeding this value. One method of reducing the accelerations on the seat itself is to suspend the seat from the side and ceiling of the fuselage rather than anchor it to the floor. The feasibility of doing this has been demonstrated in AvCIR Crash Test Number 4 and in controlled drop tests of an AvCIR experimental troop seat.[15, *] An overhead attachment gives the seat the advantage of the additional deceleration distance arising from the reduction of vertical height of the passenger cabin during impact. In addition, it makes seat retention independent of floor deformation or break-up. Obviously, a large number of seats attached to the overhead structure may require that consideration be given to this type of loading in the design of the aircraft.

Tables 7 and 9 give the floor and pelvic measurements obtained from the two H-13 helicopters. The conditions indicated are somewhat more severe than in the case of the H-25 and HUP-2 aircraft. This is due: (1) to the fact that the seats are more rigid than those used in the larger aircraft, and (2) the H-13 has much less overall deformable structure between the bottom surface of the aircraft and the seat pan.[**]

---

* As of date of the publication of this report, an AvCIR experimental troop seat and restraint system incorporating these concepts has been successfully employed in a full-scale crash test of an H-21 helicopter.

** The deformation of the landing gear and its support structure produced almost no measurable acceleration at floor level in the five helicopter tests conducted by AvCIR.

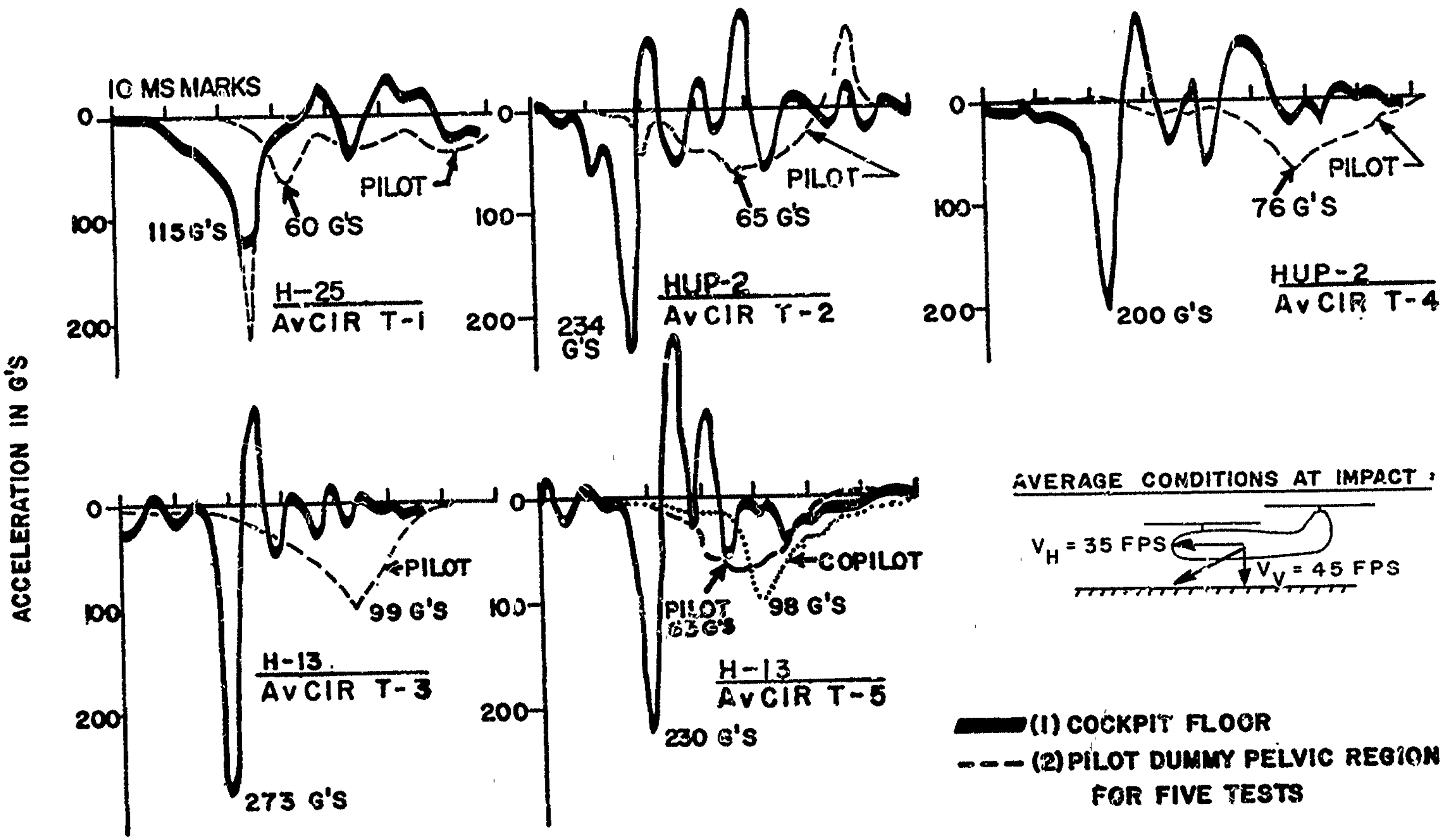


Figure 21. Vertical Accelerations Occurring in Five Helicopter Crash Tests.

Although the H-13 helicopter data is not applicable to the troop-seat problem, it is presented here since it illustrates that extremely large vertical decelerations of short duration may be expected in certain helicopter accidents. These data will also become important in extending this work on troop seats to encompass the crew seat problem.

Since much of the acceleration data obtained by NACA are available in tabular form only, it was not possible to treat the data for the fixed-wing group in the same manner as for the helicopters. However, the peak magnitudes were plotted against total pulse duration on the human tolerance curves in Figures 22 and 23. In the longitudinal (spineward) direction, the data points fall below the voluntary exposure curve. In the vertical (headward) direction, several points fall above the voluntary exposure curves; however, it is apparent that the load factors suggested above for the helicopter would, within the limits of human tolerance, resolve the fixed-wing problem.

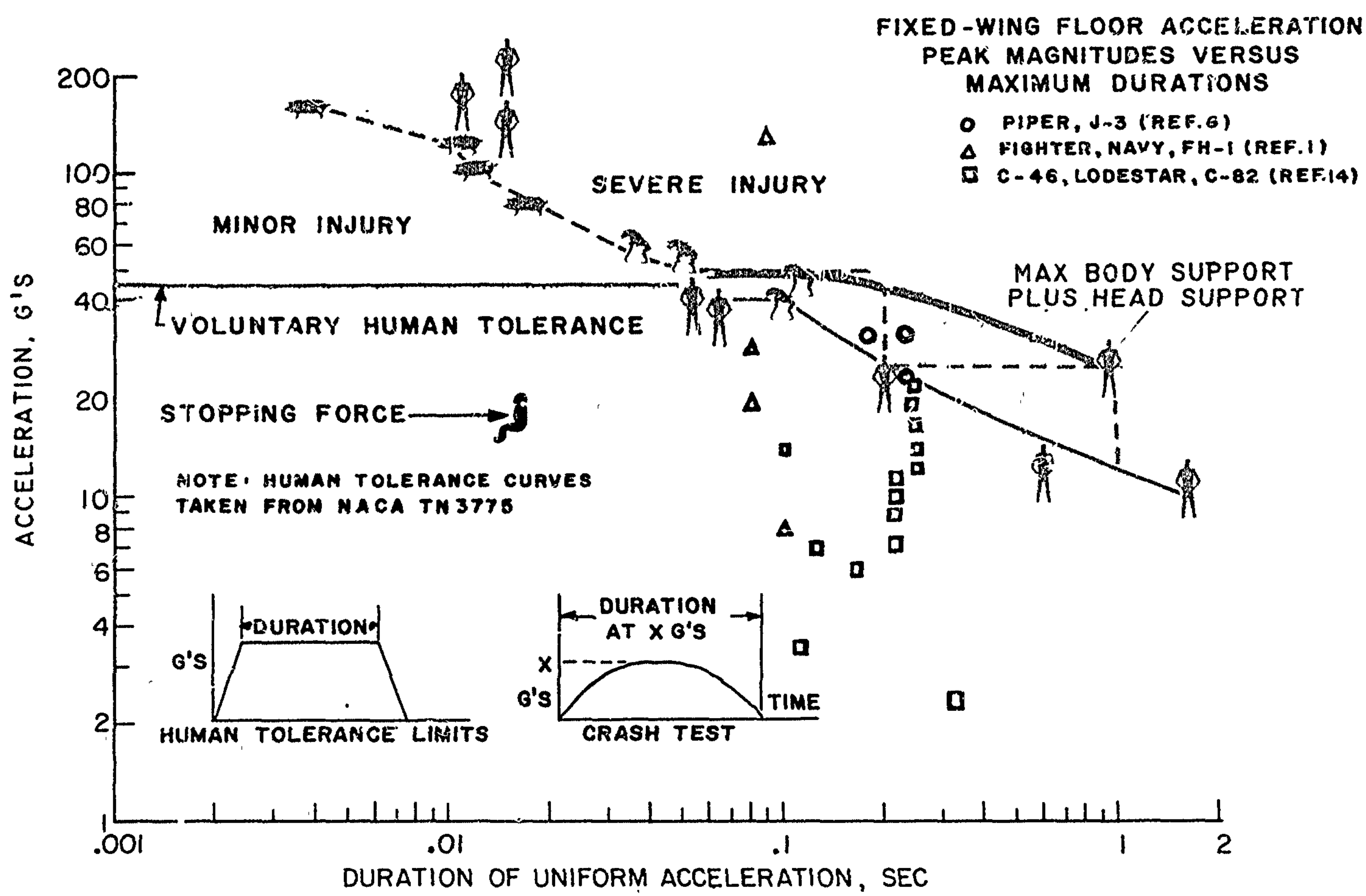


Figure 22. Fixed-Wing Floor Accelerations Versus Peak Magnitude Compared With Human Tolerance to Acceleration Perpendicular to the Spine.

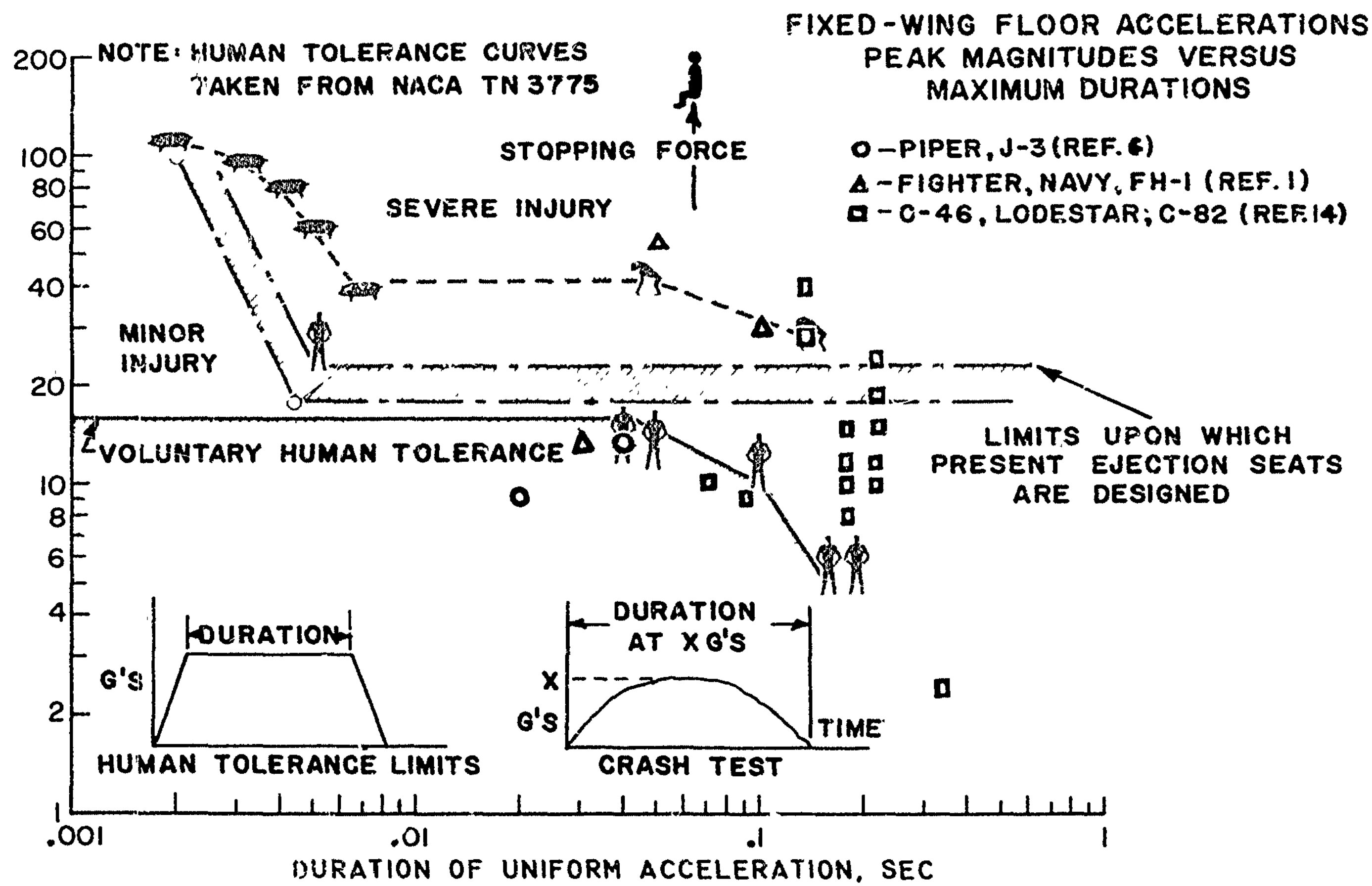


Figure 23. Fixed-Wing Floor Accelerations Versus Peak Magnitude Compared With Human Tolerance to Acceleration Parallel to the Spine.

COMPENDIUM

CONCLUSIONS

After comparing the crash test data with the limits of human tolerance to transverse, lateral, and vertical (headward) decelerations, it is concluded that the troop seat acceleration design values, selected on the basis of human tolerance alone (25G for 0.20 second and 45G for 0.10 second in the transverse and lateral directions and 25G for 0.10 second in the vertical direction), are near the optimum.

It must, however, be clearly understood that the installation of a rigid seat with a vertical design load factor of "25G" would not satisfy the requirements demanded, particularly for helicopters. Referring to Figure 21, it will be readily seen that the vertical accelerations in excess of 25G will occur at the floor level even in accidents involving moderate (40 feet per second) rates of descent. It is quite probable that even lower vertical velocities would still give peak accelerations in excess of 25G. Obviously a seat of conventional design, even though having a load factor of 25G, would be expected to fail when subjected to such loads.

To investigate the feasibility of developing a system to reduce, for example 100 to 200G which can be expected at floor level, to 25G on the occupant, it is assumed that a permanently deformable "massless cushion" having a rectangular stress-strain curve is placed between the bottom of the seat pan and the floor. There is no physical requirement that an actual "cushion" as such be used. Overhead energy absorbers such as were employed in the tests described in Reference 15 would serve as well and, further, offer the advantage of increasing the effective value of D_s in equation 2 on page 46 . Let the maximum usable strain for the "cushion" be ϵ_m as illustrated in Figure 24. Such stress-strain curves are typical of foamed or honeycombed materials and can readily be realized in mechanical systems. The acceleration of the torso mass of the occupant can be assumed to follow that of the airframe* until the acceleration reaches the design

* In this simple analysis, internal dynamic amplification due to the elasticity of the body is neglected. Many subjects have experienced the 25G maximum proposed without fatal injury and, in fact, with few injuries. Further, the dynamic properties of the deceleration system proposed (massless cushion or spring of zero constant beyond the design load) do not permit dynamic amplification of force on the body as a whole due to overshoot, provided, of course, the useable energy absorption range for the system is not exceeded.

value G_m (Figure 25). (This has been shown to be approximately true in actual tests.)[15, 25] To give the most severe condition, it is assumed here that G_m is reached in a short time interval and, thus, before appreciable reduction in the vertical velocity of the occupant has occurred. The respective acceleration pulses are shown in Figure 25.

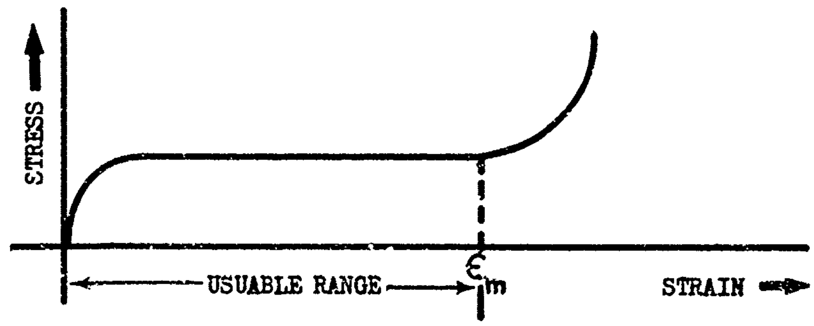


Figure 24. Assumed Stress-Strain Relation for Energy Absorber.

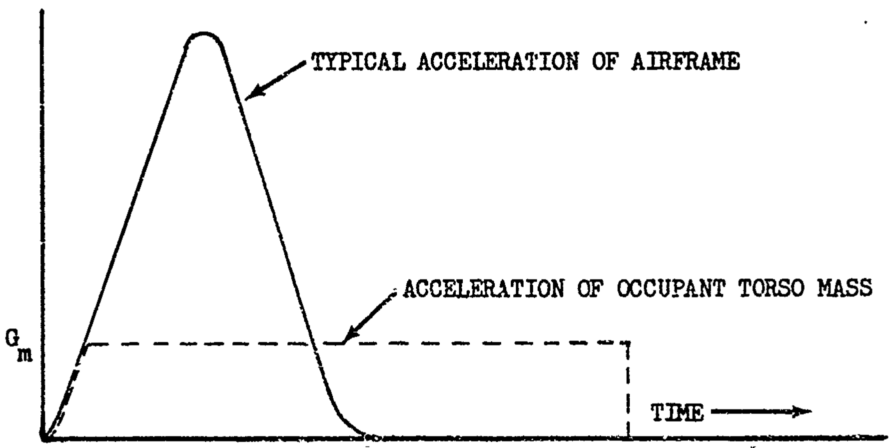


Figure 25. Assumed Acceleration of Floor and Occupant.

Subject to the above assumption, the following relationships hold:

$$Vi^2 = 2AS = 2gG_m S \quad (1)$$

$$S = \epsilon_m H + D_s \quad (2)$$

where:

V_i = Velocity at impact ---- feet per second

A = gG_m = Design acceleration for seat system --- feet per second

G_m = Design Acceleration ---- Gs

g = 32.2 feet per second per second

S = Stopping Distance ---- feet

ϵ_m = Maximum usable strain ---- percent

D_s = Effective deformation in aircraft structure ---- feet

H = Cushion thickness (or length of mechanical energy absorber) ----- feet

Eliminating "S" in equations (1) and (2) gives:

$$H = \frac{1}{\epsilon_m}\left[\frac{V_i^2}{2gG_m} - D_i\right] \quad (3)$$

This equation is plotted in Figure 26.

As a control or check point, the result of a test conducted by AvCIR during one of the HUP-2 drops is superimposed on Figure 26. In the test, a copilot dummy, supported on 14 inches of paper honeycomb at V_i = 43 feet per second, gave experimental values of $G_m \doteq 35$ and $\epsilon \doteq 50$ percent. Figure 26 shows that a theoretical cushion thickness of 1.3 feet (15.6 inches) would be required to maintain 35G to 50 percent strain. This satisfactorily close agreement between experimental and theoretical values indicates the reliability of equation 3 and Figure 26.

An examination of Figure 26 will immediately show that with vertical impact velocities of V_i equal to 30 to 50 feet per second, ϵ_m = 80 percent, G_m = 25G, and D_i = 3 inches*, vertical travel or deformation of the "seat system" must be of the order of 8 to 24 inches. Such deformation is attainable or approachable if the 15 inches of space below the normal seat is <u>effectively</u> utilized. It is important to recognize that the space alone is worthless and that the seat system must <u>maintain</u> the proposed G_m on the occupant torso during the complete travel. This, then, is the previously mentioned added

* These are realistic values.

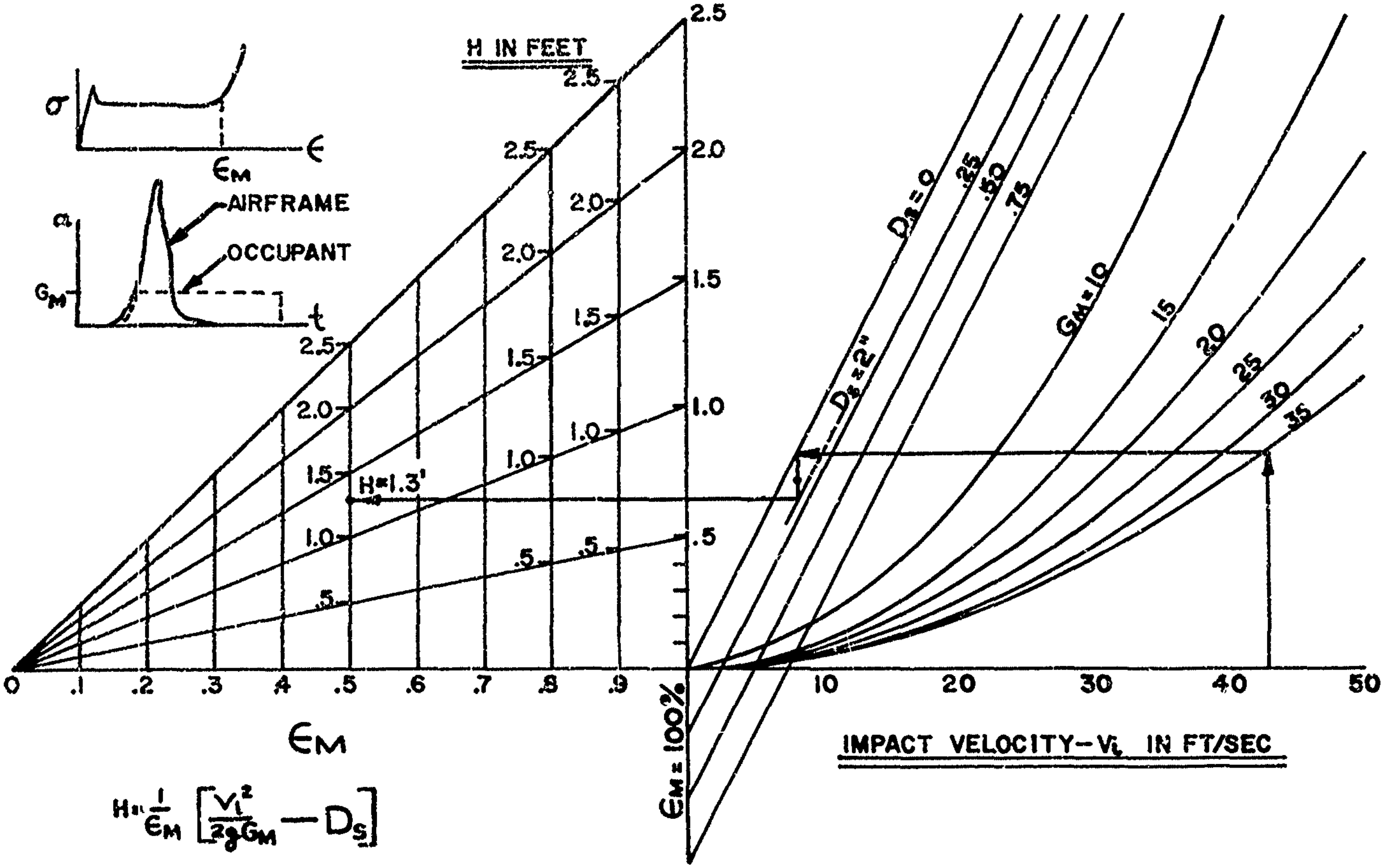


Figure 26. Cushion Thickness H As a Function of G_m, V_i, ϵ_m, D_s.

requirement beyond the specification of a given design load factor.

RECOMMENDATIONS

The following recommendations are presented in light of the foregoing discussions, with particular consideration being given to the experimentally obtained human tolerance data and to the experimentally obtained acceleration environment for light- and medium-weight rotary-wing aircraft and C-46 and C-119 cargo transports. They should be considered subject to modification upon the presentation of new data, but are now believed to be the best compromises possible in view of existing evidence.

It is recommended that the appropriate military specifications applicable to troop seats for rotary-wing aircraft be modified to reflect the following requirements:

1. Longitudinal and Lateral Design Loads. The seat, its support system, and the occupant restraint system should, in combination, be capable of maintaining 25G for 0.20 second and 45G for .1 second in the pelvic region of a suitable dummy having a weight and mass distribution of that of the heaviest occupant expected. (See page 51, "effective mass".)

2. Vertical (Headward) Design Loads. The seat, its support system, and the occupant restraint system should, in combination, be capable of continuously maintaining 25G ± 5G (see page 52, effect of varying occupant weight) in the pelvic region of the dummy described in paragraph 1, while deforming through at least 12 inches of vertical travel with respect to the airframe and, where possible, up to 15 inches or more of vertical travel. This is an energy absorption requirement and the mechanism in which the energy is absorbed is unimportant. Through appropriate design, this can conceivably be done by (a) use of mechanical devices, (b) by use of crushable materials, or (c) in the seat structure itself. Whatever the method, the acceleration as a function of displacement should be constant at 25G within the specified 5G tolerance in order that the most effective use can be made of the limited space between seat pan and floor.

   In addition, the seat, its support system, and the occupant restraint system should, in combination, be capable of sustaining 25G for 0.10 second without gross failure.

3. Manner of Loading. The "seat system" should be capable of satisfying requirements 1 and 2 both simultaneously and separately without loss of restraint of the occupant during or after impact and in such manner as to maintain alignment of the occupant torso in a normal sitting position. Further, the system, in event of failure due to loads in excess of the design values, should present no projections or cutting edges.

4. Restraint System. The restraint system should include a lap belt and shoulder harness. Additional body support in the form of thigh and chest straps should be considered where consistent with operational requirements of the aircraft and personnel aboard.

5. Application to Fixed-Wing Aircraft. A considerable amount of impact acceleration data presently exists as a result of the experimental work done by NACA.[10] The experiments conducted, however, were generally directed toward the crash-fire problem and were of such nature that they generally gave relatively low vertical decelerations as compared with known human tolerance to headward pulses. Modifications of either the impact conditions or the type of airframe structure would very probably change the end results.

   Military troop transports presently in use and those planned for the future are of the V/STOL types, required to operate on short, unimproved runways. In addition, military troop transports generally do not have large cargo compartments between the floor structure and bottom of the fuselage. It can, therefore, be assumed that the operating procedures required, coupled with the lack of energy absorption structure beneath the floor of the aircraft, will result in accidents in which high vertical accelerations will be imposed upon the occupants of these military transport aircraft. It is, therefore, probable that the requirements set forth in paragraphs 1 through 4, specifically including paragraph 2, apply both to fixed- and rotary-wing aircraft. It is, thus, recommended that, for the present, no distinction with regard to crashworthiness be made in the specifications for troop seats for these two types of aircraft.

OTHER CONSIDERATIONS RELATIVE TO MODIFICATION OF CURRENT MILITARY SPECIFICATIONS

It is obvious that no practical seat restraint system will ever be designed which will permit all occupants of an aircraft to survive all accident situations. It is apparently within present technological capabilities, however, to increase greatly the survival rate with only moderate weight and cost penalties. Knowledge and experience in this field, though limited, will grow provided a first step is taken.

The following comments are pertinent to the recommendations of the preceding section. They are presented for information purposes only and should appear in the final military specifications only after careful consideration of paragraph 2 below.

1. Military Specification. Insofar as possible, the initial specifications for an experimental troop seat meeting the requirements set forth in the preceding section should be as flexible as possible beyond those requirements in order to allow industry to exercise a maximum of ingenuity in the development of a suitable system.

2. Effective Mass Distribution. The recommended design loads appearing in the recommendations, that is,

Longitudinal and Lateral:		45G for 0.10 second and 25G for 0.20 second
Vertical:		25G ± 5G with a 12-inch minimum travel,
	and	25G for 0.10 second

are the actual values desired in the pelvic and chest masses of the occupant. In the design of the seat restraint system, the effective mass of the torso of the occupant thus becomes important and must be known. For example, a 200-pound occupant, with feet resting upon the floor, obviously does not apply an effective weight of 200 pounds to the seat. It is estimated that only 75 to 80 percent of the total weight of a normally seated occupant is supported by the seat in a vertical impact of the duration required here. Experimental work is probably needed in this area to determine these values under a variety of conditions.

3. Effect of Varying Occupant Weight. A change in occupant weight from a given standard design value will, unless suitable provisions are designed into the system to allow for variable occupant weight, affect the constant level of deceleration applied to the subject during compression of the energy absorber required in the vertical system for attenuating headward decelerations. Figure 27 illustrates this effect:

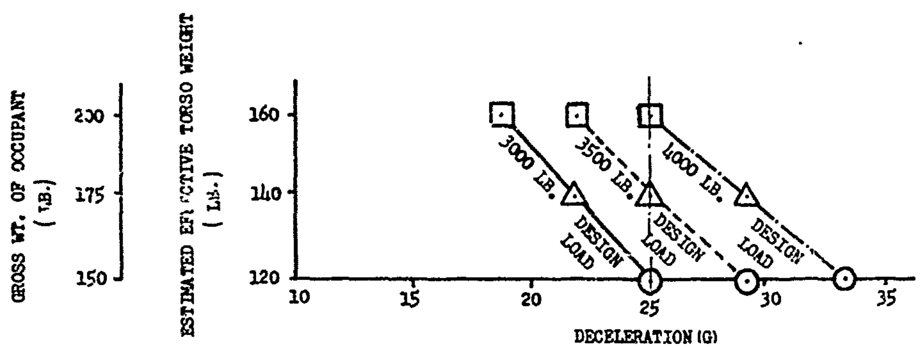


Figure 27. Effect of Varying Occupant Weight on the Constant Level of Deceleration.

——— System designed to give 25G on 150-pound occupant (gross weight)

– – – – System designed to give 25G on 175-pound occupant (gross weight)

—·—· System designed to give 25G on 200-pound occupant (gross weight)

A compromise based on statistical average weights will leave the underweight or overweight occupants with reduced protection. Provision for individual adjustment in mechanical systems would be possible.

4. Energy Absorption Requirement. This will be the most difficult requirement to meet, but it is quite probably the most important one for rotary-wing and V/STOL aircraft. It cannot be omitted if maximum protection is to be provided. Problems which will arise and must be solved include:

   a. Maintenance of alignment of occupant during absorber travel.

   b. Maintenance of tight restraint system during absorber travel.

5. Overhead Attachments. This type of attachment for troop seats (contrasted with floor attachments)[15, 19, 24] offers considerable advantage and should be given special consideration. Such installations would naturally affect the structural design of the upper portion of the fuselage.

6. Contact Injuries. Both the structure of the aircraft and of the seat system itself must be given primary consideration for the elimination of injury-producing protrusions.

7. Effect of Seat Occupancy. Rows of seats or multiple seats must be constructed to provide the protection specified in the foregoing sections, even though only one man occupies the seat or row of seats. Unoccupied adjacent seats must not provide a source of injury after the vertical deformation of the energy absorber has begun.

8. Combat Packs. Packs, if worn while in flight, should be directly supported by the seat; that is, no load path from seat through the spine to the pack should exist. Obviously, additional pack weight in the seat provides a means of varying effective torso mass as discussed in paragraph 3. For the extremely underweight occupant, if properly employed, the "in seat" pack could be used to advantage.

9. The specification of a dynamic design load condition, i.e. X G's for Y seconds will require dynamic proof testing for verification of performance and quality control.

REFERENCES

1. Acker, L. W., et al, Accelerations In Fighter Airplane Crashes. NACA RM E57G11, National Advisory Committee for Aeronautics, Washington, D. C., 4 November 1957.

2. Beeding, E. G., Jr., Mosely, J. D., Human Deceleration Tests, AFMDC-TN-60-2, Holloman AFB, New Mexico, January 1960.

3. Bruggink, G. M., et al, U. S. Army AC-1 DeHavilland Caribou Evaluation, TRECOM Technical Report 60-62, AvCIR 14-PV-121, Aviation Crash Injury Research, Phoenix, Arizona, October 1960.

4. Bruggink, G. M., Limits of Seat Belt Protection During Crash Decelerations, AvCIR 61-8, Aviation Crash Injury Research, Phoenix, Arizona, September 1961.

5. DeHaven, H., "Mechanical Analysis of Survival in Falls from Heights of Fifty to One Hundred and Fifty Feet", Reprinted from War Medicine, Vol. 2, pp 586-596, July 1942.

6. Eiband, A. M., et al, Accelerations and Passenger Harness Loads Measured in Full-Scale Light-Airplane Crashes. NACA Technical Note 2991, National Advisory Committee for Aeronautics, Washington, D. C., August 1953.

7. Fryer, D. I., Aircraft Passengers - Seat Design and Crash Survival, FPRC 1055, Institute of Aviation Medicine, RAF, Farnborough, August 1958.

8. Goldman, D. E., Von Gierke, H. E., The Effects of Shock and Vibration on Man, Lecture and Review Series No. 60-3, Naval Medical Research Institute, Bethesda, Maryland, January 1960.

9. Hegenwald, J. F., Jr., Oishi, S., Human Tolerance to Accelerations: A Practical Tool for the Engineer, Report No. NA-57-425, North American Aviation, Inc., Los Angeles, California, 6 May 1957.

10. Holcomb, G. A., "Impact Studies of the United States Aerospace Industry", Symposium on Impact Acceleration Stress, Brooks Air Force Base, San Antonio, Texas, Stanley Aviation Corporation, Denver, Colorado, 27-29, November 1961.

11. Lewis, S. T., Stapp, J. P., "Human Tolerance to Aircraft Seat Belt Restraint", Reprinted from The Journal of Aviation Medicine, Vol. 29, Pages 187-196, March 1958.

12. Pesman, G. J., Eiband, A. M., Crash Injury, NASA Technical Note 3775, National Aeronautics and Space Administration, Washington, D. C., November 1956.

13. Pinkel, I. I., "Aircraft Seating, Forward Facing or Rearward?" Mechanical Engineering, February 1960.

14. Preston, G. M., Pesman, G. J., Accelerations in Transport-Airplane Crashes, NACA TN4158, National Advisory Committee for Aeronautics, Washington, D. C., February 1958.

15. Robertson, S. H., Dynamic Test of an Experimental Troop Seat, TRECOM Technical Report 62-48, AvCIR 62-5, Aviation Crash Injury Research, Phoenix, Arizona, June 1962.

16. Roegner, H. F., Knowles, W. R., U. S. Army H-21C Shawnee Helicopter Accident Report, Luray, Virginia, TRECOM Technical Report 60-14, AvCIR 11-PR-112, Aviation Crash Injury Research, Phoenix, Arizona, February 1960.

17. Roegner, H. F., Carroll, J., U. S. Army HU-1A Bell Iroquois Helicopter Accident Report, Fort Carson, Colorado, TRECOM Technical Report 60-72, AvCIR 12-PR-122, Aviation Crash Injury Research, Phoenix, Arizona, December 1960.

18. Roegner, H. F., et al, U. S. Army HU-1A Bell Iroquois Helicopter Accident Report, Fort Bragg, North Carolina, TRECOM Technical Report 60-71, AvCIR 13-PR-123, Aviation Crash Injury Research, Phoenix, Arizona, December 1960.

19. Smith, L. D., Crash or Ditching Seat for B-47 Aircraft, WCRDC-666-25D, Wright Air Development Center, Wright-Patterson AFB, Dayton, Ohio, 31 December 1951.

20. Stapp, J. P., "Jolt Effects of Impact on Man", Aerospace Medical Division (AFSC) Brooks AFB, San Antonio, Texas.

21. Stapp, J. P., "Human Tolerance to Decelerations: A Summary of 116 Runs", Journal of Aviation Medicine, Vol. 22, No. 1, pp. 42-45, 85, February 1951.

22. Turnbow, J. W., U.S. Army H-25 Helicopter Drop Test, TRECOM Technical Report 60-75, AvCIR 1-TR-124, Aviation Crash Injury Research, Phoenix, Arizona, December 1960.

23. U.S. Army H-34A Accident Report, U.S. Army Ranger Camp, Dahlonega, Georgia, 21 May 1959.

24. U.S. Army HUP-2 Helicopter Drop Test, 14 June 1961. Aviation Crash Injury Research, Phoenix, Arizona. Report to be published.

25. U.S. Army HUP-2 Helicopter Drop Test, 9 August 1961. Aviation Crash Injury Research, Phoenix, Arizona. Report to be published.

26. U.S. Army H-13 Helicopter Drop Tests, 17 June 1961 and 3 August 1961. Aviation Crash Injury Research, Phoenix, Arizona. Report to be published.

APPENDIX
ACCIDENT EXPERIENCE WITH MILITARY-SPECIFICATION TROOP SEATS

ACCIDENT A

During the crash sequence, the aircraft rolled approximately 90 degrees to the left, scraping down the sides of trees approximately 40 feet in height. The aircraft impacted on its left side. Initial ground contact occurred on the left side of the pilot's compartment, forward of the copilot's seat, with the aircraft in a 3-5 degree nose down attitude in relation to the ground. After initial impact, the rear section of the aircraft settled with the tail cone wedged between several trees.[16]

Troop Seat Failures.

The basic structure in the main cabin area remained completely intact. In spite of the intact condition of this basic structure (indicating moderate crash forces), a number of the seats and seat belts failed, resulting in numerous injuries to the occupants of the main cabin.

Investigation revealed that six seats failed, two on the left, or low side of the aircraft, and four on the right, or high, side. The two failures on the left side of the cabin consisted of failure of the seat legs. These failures probably occurred when the occupants from the right side were thrown against them. The four seat failures on the right side resulted mainly from a number of breaks in the rear support beam. These failures occurred at the points where the seat support beam is drilled to accommodate either a seat belt attachment (D-ring) or a wall anchorage. These holes are located approximately every 18 inches along the length of the support members. In addition to the rear support beam failures (Figures 4 and 5), there were also numerous leg and diagonal support member failures of the seats on the right, or high, side.

The investigation also revealed six seat belt anchorage failures on the right, or high, side of the cabin. These failures also resulted from failure of the rear support beam. In this installation, D-rings are attached to the rear support beam through one of the holes cited above and the safety belts are snapped to these D-rings. Two safety belts are frequently attached to one D-ring, that is, the left safety belt of one occupant and the right safety belt of another occupant are both attached to the same ring. A single failure, under such conditions, permits two occupants to be thrown free in the cabin area. Attachment of the seat belts in this manner, combined with the forces generated by the occupant in the seats, contributed to the numerous failures of the rear support beam in this accident (Figure 5).

In summary, the seat failures experienced in this accident were the result of poor design characteristics of the seats in combination with the low design load factors which are called for in the current specifications.

ACCIDENT B

During the approach to an intended landing site, the pilot observed an obstruction and initiated a climbing turn to the right. At approximately 270 degrees of the turn and 300 feet of altitude, a partial power failure occurred. The pilot immediately actuated the increase power switch. After a momentary increase, partial or full loss in power occurred.[17]

Seat Failures.

The most severe damage to the interior section of the aircraft was experienced in the cabin section. Failure of one of the troop seats and penetration of the rear bulkhead by the transmission are significant from a crash injury point of view. At impact, the forward support beam on seat R-1 failed. In addition to the failure of the forward support beam, the upper support beam of seat R-1 (attached to the firewall by means of four bolts inserted through drilled holes in the attachment) also failed (Figure 6). This attachment supports the seat back webbing. Failures frequently occur at these points under relatively low crash forces. It is obvious that a considerable load was imposed on this support by the transmission failure (Figure 6); however, numerous failures of this type of seat have been noted in other accidents in which the transmission failure was not a contributing factor.

ACCIDENT C

The pilot, having entered the downwind leg for the intended landing site, felt the aircraft settle and immediately noticed a drop in engine rpm while at approximately 200 feet. He immediately lowered the nose to maintain rotor rpm and committed the aircraft to a forced landing.[18]

Seat Failures.

Standard military troop seats, designed to MIL-S-5804B, were installed on this aircraft.

The left rear two-man seat was occupied by one passenger on the outboard side. At impact, the seat pan ripped from the rear support beam. This support beam pulled out of the clamp on the left side of the bulkhead and moved 2 inches to the right. The hooks, which suspend the seat back from the upper support beam, pulled free from the upper support beam. The upper support beam failed at a drilled hole where it is attached to the rear bulkhead. Failure of the seat pan, followed by a downward force exerted by the occupant caused the forward beam to break at a drilled hole near the diagonal-brace attachment.

The right rear two-man seat was occupied by two passengers. At impact, the floor just ahead of this seat buckled upward as the aircraft impaled itself on a tree stump. The upheaval of the floor, plus the downward force exerted by the two passengers, caused distortion and failure of the seat legs, permitting the seat pan to come into contact with the handle of the hydraulic pump on the ground handling wheels stowed under the seat and causing the seat pan to rip longitudinally. The seat spreader under the inboard occupant broke and the diagonal brace failed. The seat support beam also failed on this seat (Figures 7 and 8).

An analysis of the troop seat failures in this accident suggests failure at moderate impact forces.

ACCIDENT D

Following a maximum-performance takeoff and after reaching a height of approximately 75 feet, the pilot noticed a drop in engine rpm. He used the appropriate techniques to alleviate this situation, but was unable to maintain altitude. The aircraft began to settle into the trees and the pilot executed a flare to cushion the impact.[23]

Seat Failures.

Ten of the eleven occupied troop seats failed in this moderate-impact-accident. This accident was very similar to Accident A in regard to the aircraft's impacting on its side with the impact forces being reduced by the trees and soft terrain. Seat failures were also similar in that numerous failures occurred in the front support beams, seat legs, and seat backs (Figures 9 and 10).

Injuries were sustained in this accident due to the numerous seat failures.

Since impact loads on the inhabitable area were moderate, as evidenced by the practically intact cargo compartment, it is obvious that the design strength of the seats was insufficient to take advantage of the hull strength. CAM 3.386-1 states: "Close study of crash results show that the human body, when properly supported, can tolerate crash forces which exceed those necessary to demolish contemporary aircraft structure."

DISTRIBUTION

USCONARC	9
First US Army	3
Second US Army	2
Third US Army	2
Fourth US Army	1
Sixth US Army	1
USAIC	2
USACGSC	1
USAWC	1
USAATBD	1
USAARMBD	1
USAAVNBD	1
USATMC(FTZAT), ATO	1
USAPRDC	1
DCSLOG	4
Rscn Anal Corp	1
ARO, Durham	2
OCRD, DA	2
USATMC Nav Coord Ofc	1
NATC	2
ARO, OCRD	2
CRD, Earth Scn Div	1
CG, USAAVNC	2
USAAVNS, CDO	1
DCSOPS	1
OrdBd	1
USAQMCDA	1
QMFSA	1
CECDA	1
CofT	8
USATCDA	1
USATB	1
USATMC	20
USATC&FE	4
USATSCH	5
USATRECOM	41
USA Tri-Ser Proj Off	1
USATTCA	1
TCLO, USAABELCTBD	1
USASRDL LO, USCONARC	2

USATTCP	1
OUSARMA	1
USATRECOM LO, USARDG (EUR)	2
USAEWES	2
TCLO, USAAVNS	1
USATDS	5
USARPAC	1
EUSA	1
USARYIS/IX CORPS	2
USATAJ	6
USARHAW	3
ALFSEE	2
USACOMZEUR	3
USACARIB	4
AFSC (SCS-3)	1
APGC(PGAPI)	1
Air Univ Lib	1
AFSC (Aero Sys Div)	2
ASD (ASRMPT)	1
CNO	1
CNR	3
BUWEPS, DN	5
ACRD(OW), DN	1
BUY&D, DN	1
USNPGSCH	1
CMC	1
MCLFDC	1
MCEC	1
MCLO, USATSCH	1
USCG	1
USASGCA	1
Canadian LO, USATSCH	3
BRAS, DAQMG(Mov & Tn)	4
USASG, UK	1
NAFEC	3
Langley Rsch Cen, NASA	3
Geo C. Marshall Sp Flt Cen, NASA	1
MSC, NASA	1
NASA, Wash., D. C.	6
Ames Rsch Cen, NASA	2
Lewis Rsch Cen, NASA	1
Sci & Tech Info Fac	1
USGPO	1

ASTIA	10
HUMRRO	2
US Patent Ofc, Scn Lib	1
DAA	3
ODCSOPS, ASD	2
ODCSPER, DS	1
USAMCAFO	2
BMS, AMSFTBr	2
BMS, AMTDiv	1
SG, AvnBr	5
AFIP	2
Hq, USMC	1
ONRsch	2
CNAFB, USAFDFSR	1
USABdAvnAccRsch	5
USAAHRU	1
USAR, USNASC	1
DUSNASC, NAS	2
NavAMC	3
NADC	1
WADD	2
ASML	2
DCA, USATRECOM	1
NASA Hq	1
CARI, FAA	2
NLM	2
AF Fli Ts Cen	2
HUSTWO	2
ARDS, FAA	2
BFS, FAA	2
BAM, FAA	2
NAFEC	1
BofS, CivAeroBd	2
APD, USPHS	2
APRSS, DivRschGr	2
FSF	5
AvCIR	100
MOCOM	3

Aviation Crash Injury Research, Phoenix, Arizona, MILITARY TROOP SEAT DESIGN CRITERIA, J. W. Turnbow, Ph. D., V. E. Rothe, G. M. Bruggink, H. F. Roegner, TCREC Technical Report No. 62-79, November 1962, 65 pp. (Contract DA 44-177-TC-802) USATRECOM Task 9R95-20-001-01

(Unclassified Report)

Report is made of results of careful analysis of military troop seat deficiencies conducted over a three-year period. Available data have been translated (continued)

UNCLASSIFIED

1. Military Troop Seat Design Criteria

2. Contract DA-44-177-TC-802

Aviation Crash Injury Research, Phoenix, Arizona, MILITARY TROOP SEAT DESIGN CRITERIA, J. W. Turnbow, Ph. D., V. E. Rothe, G. M. Bruggink, H. F. Roegner, TCREC Technical Report No. 62-79, November 1962, 65 pp. (Contract DA 44-177-TC-802) USATRECOM Task 9R95-20-001-01

(Unclassified Report)

Report is made of results of careful analysis of military troop seat deficiencies conducted over a three-year period. Available data have been translated (continued)

UNCLASSIFIED

1. Military Troop Seat Design Criteria

2. Contract DA-44-177-TC-802

Aviation Crash Injury Research, Phoenix, Arizona, MILITARY TROOP SEAT DESIGN CRITERIA, J. W. Turnbow, Ph. D., V. E. Rothe, G. M. Bruggink, H. F. Roegner, TCREC Technical Report No. 62-79, November 1962, 65 pp. (Contract DA 44-177-TC-802) USATRECOM Task 9R95-20-001-01

(Unclassified Report)

Report is made of results of careful analysis of military troop seat deficiencies conducted over a three-year period. Available data have been translated (continued)

UNCLASSIFIED

1. Military Troop Seat Design Criteria

2. Contract DA-44-177-TC-802

Aviation Crash Injury Research, Phoenix, Arizona, MILITARY TROOP SEAT DESIGN CRITERIA, J. W. Turnbow, Ph. D., V. E. Rothe, G. M. Bruggink, H. F. Roegner, TCREC Technical Report No. 62-79, November 1962, 65 pp. (Contract DA 44-177-TC-802) USATRECOM Task 9R95-20-001-01

(Unclassified Report)

Report is made of results of careful analysis of military troop seat deficiencies conducted over a three-year period. Available data have been translated (continued)

UNCLASSIFIED

1. Military Troop Seat Design Criteria

2. Contract DA-44-177-TC-802

into terminology, meaningful to engineering personnel. Utilization of the information presented would produce a seat representative of the current state of the art and greatly reduce incidence of needless injury and death attributable to troop seat failure in survivable-type Army aircraft accidents.

into terminology, meaningful to engineering personnel. Utilization of the information presented would produce a seat representative of the current state of the art and greatly reduce incidence of needless injury and death attributable to troop seat failure in survivable-type Army aircraft accidents.

into terminology, meaningful to engineering personnel. Utilization of the information presented would produce a seat representative of the current state of the art and greatly reduce incidence of needless injury and death attributable to troop seat failure in survivable-type Army aircraft accidents.

into terminology, meaningful to engineering personnel. Utilization of the information presented would produce a seat representative of the current state of the art and greatly reduce incidence of needless injury and death attributable to troop seat failure in survivable-type Army aircraft accidents.